AD-A105 584 HONEYWELL SYSTEMS AND RESEARCH CENTER MINNEAPOLIS MN F/G 14/2
ANALYSIS OF SELECTED MULTISENSOR COMBINED DISPLAY CONCEPTS.(U)
MAR 80 C P GRAF, R A NORTH, A JOSEFOWITZ N00014-77-C-0684

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ANALYSIS OF SELECTED MULTISENSOR COMBINED DISPLAY CONCEPTS

Systems & Research Center
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MARCH 1980

Final Report: Phases II and III September 1977 - March 1980

Office of Naval Research
Department of the Navy
800 N. Quincy St.
Arlington, Virginia 22217

81 10 14

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SECURITY CLASSIFICATION OF THIS PAGE (WHEN DATA ENTERED)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOV'T ACCESSION NUMBER AD-A105584	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (AND SUBTITLE) Analysis of Selected Multisensor Combined Display Concepts		5. TYPE OF REPORT/PERIOD COVERED Final Report 9-30-77-
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(S) C. P. Graf, R. A. North, A. Josefowitz		8. CONTRACT OR GRANT NUMBER(S) N00014-77-C-0684
9. PERFORMING ORGANIZATIONS NAME/ADDRESS Honeywell Systems & Research Center, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413		10. PROGRAM ELEMENT,PROJECT,TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME/ADDRESS ONR, Department of the Navy, 800 N. Quincy Street, Arlington, VA 22217		12. REPORT DATE March 1980
		13. NUMBER OF PAGES 111
14. MONITORING AGENCY NAME/ADDRESS (IF DIFFERENT FROM CONT. OFF.)		15. SECURITY CLASSIFICATION (OF THIS REPORT) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (OF THIS REPORT)

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17. DISTRIBUTION STATEMENT (OF THE ABSTRACT ENTERED IN BLOCK 20, IF DIFFERENT FROM REPORT)

Distribution Unlimited

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

Multisensor displays
Combined displays
RADAR
FLIR
Aircraft mission profiles
Color displays

20. ABSTRACT (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

This report contains Combined Multisensor Display Concepts for navigation and target detection/recognition in attack aircraft. Missions and sensors were reviewed and an experiment was conducted to compare multisensor concepts against multidisplay and multi-function displays.

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FOREWORD

This report documents work performed under Contract No. N00014-77-C-0684, the Office of Naval Research, 800 North Quincy Street, Arlington, Virginia. Data covers the second and third phases of a three-phase program to evaluate a variety of multisensor, combined-display concepts for implementation and for their effect on operator performance. The first phase was a broad review of various methods of combining two different sensor inputs on one display. The results and analyses thereof were presented in the final report entitled "Feasibility of Multisensor Combined Displays", prepared under ONR Contract Number N00014-76-C-0797 and published in December 1976. In the second phase, reported in this document, the scope has been narrowed somewhat. Several specific concepts were selected, a mission scenario developed, the information expected from specific sensors analyzed, and hypothetical examples of combined sensor imagery were prepared. Finally, a test plan was prepared for evaluating these concepts and determining their effectiveness in terms of operator performance.

In the third phase, also contained in this document, stimulus material was prepared and an experiment was conducted according to the test plan. The test compared two multisensor display concepts (color and black and white) against two current display configurations (multifunction and multidisplays). The data from the test was analyzed, recommendations for configuring multisensor displays were developed, and a new multisensor display configuration was developed.

The authors would like to acknowledge the support and encouragement provided by Commander S. Holmes, and Mr. J. Tremble, technical monitors and Commander D. Hanson of ONR. The authors express appreciation to Mr. Mark Voth for software development, Dr. Marjorie Krebs for manuscript preparation, Dr. Tom Edman and Ms. Ann Melgren for conducting the experiment; Mr. Roger Eastey and Mr. Jon Merkouris for hardware development, Mr. Ray Roberts for photography and Mr. Ron Rivard of Imperial Helicopters for the low-level flights.

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INTRODUCTION AND SUMMARY

INTRODUCTION

Interest in multisensor combined displays has arisen from a variety of different sources. First, since cockpit space is severely limited, any way of reducing space for displays while still maintaining the required information has considerable appeal. Secondly, the pilot/operator workload is constantly increasing as mission profiles for high-performance aircraft become more complex and demanding. Multisensor combined displays provide the potential for both conserving cockpit space and, at the same time, reducing the operator's workload by consolidating and integrating information from two different sources (sensors) onto one display surface.

Advances in display technology and image processing techniques have recently made such a concept feasible. Given that it is electronically possible to combine on one display information from two or more sensors, the question then becomes one of how such information can be meaningfully integrated. For example, if one were to consider combining forward-looking infra-red (FLIR) imagery with radar imagery on one display surface, a number of questions and problems immediately arise. The range, resolution, and field of view differences between the two sensors, for example, suggest that a simple superimposition of the two sensor outputs would create interpretation problems for the operator. Since the goal is to reduce workload and enhance performance, the entire process of combining information must be carefully analyzed and implemented.

This report covers the second phase of a three-phase program sponsored by the Office of Naval Research. Phase I (ONR Contract Number N00014-76-C-0797) addressed feasibility issues. Various methods of combining sensor information were discussed and preliminary evaluations made. Phase II, was concerned with definition and the preliminary design of several combined display concepts. Phase III was an evaluation of these Phase II concepts in terms of operator performance.

To define the techniques most suitable for combining multiple sensors into one displayed image, it was necessary in Phase II to limit the scope by performfing the following analytical tasks:

1) Mission scenarios were developed using the Navy's current and projected attack aircraft as the sensor platform. The emphasis was on defining the operator's information requirements during critical mission phases.

2) FLIR and radar were selected as the primary sensors and their characteristics defined. Additional sensors may be added and, in some instances, Low Light Level Television (LLLTV) substituted for the FLIR sensor.

3) Several different concepts for combining specified sensor information were selected. These concepts made use of both color and black-and-white displays. Photographic examples illustrating these concepts were prepared.

4) A test plan was prepared for evaluating these combined display concepts. The plan involved both analytical and experimental evaluations. The experimental portion realistically simulated the combined displays in a dynamic scenario. Operator target acquisition was one basis for comparison. The actual test was conducted during Phase III.

During Phase III the following tasks were performed:

1) Background imagery for the stimulus material was collected by flying a helicopter over a predescribed path in a rugged and uninhabited area along Minnesota's North Shore.

2) Software was developed to produce the simulated combined and uncombined display conditions.

3) The image processing facility consisting of a Honeywell Level 6 computer and a Stanford Technology Model 70 imagery system was used to produce identical 5-minute segments of multisensor color combined display, multisensor black and white combined display, and uncombined individual IR and PPI radar display.

4) The Man Computer Laboratory was used to conduct the experiment which included a point-of-impact task, a target recognition task and a secondary workload task. Target recognition used a voice recognition system.

5) The data was analyzed using statistical techniques to determine the advantages and problems of combined displays.

6) Recommendations were generated to aid the configuration of combined multisensor displays. An advanced combined multisensor concept for high-speed penetration and pop-up was developed.

The product of each of the above tasks is described in detail in the remainder of this report.

SUMMARY

The analytical and experimental data studied under this effort indicates that combined multisensor displays may offer significant improvements in mission profiles in the following ways:

- Improving navigation
- Permitting lower altitude operation
- Increasing the number of targets detected and recognized
- Reducing time to detect and recognize targets
- Improved weapon delivery
- Reduce pilot workload

In conclusion, combined multisensor displays provide a high-leverage methodology (significant improvements with a minimum investment) to improve the pilot/aircraft interface which in turn produces significant improvements in the mission profile.

SECTION 2
DEVELOPMENT OF A MISSION SCENARIO

The analysis of representative missions within the context of this study had a two-fold purpose:

1) To determine where a multisensor combined display might be beneficially employed

2) To provide a framework for evaluating the selected combining concepts in Phase III

Meeting the first objective required a detailed look at where and how the various sensors are currently being used in typical combat missions. It was necessary to determine the operator's specific tasks and information requirements during the course of a variety of missions. Under which circumstances were multiple sensor inputs used? What types of information was the operator attempting to locate or integrate across the several sensor inputs? An understanding of the operator's information requirements eased the understanding of how the combined display could enhance information extraction. A variety of missions were reviewed, as discussed below.

MISSIONS

The multisensor concepts developed during this effort must benefit the projected mission profiles. A review of both operational and functional time sequences will assist in determining the strengths and weaknesses of the current multisensor concepts.

The most useful data sources on the tactical aircraft missions are the test material, and the staff at the Fighter Weapons School at Nellis AFB. This information includes the Flight Manuals; Flight Crew Checklists and Performance Data Manuals for current aircraft; and Technical Orders for the aircraft systems. All of these sources were used to prepare the mission profiles and requirements. The most current definitions of air-to-ground missions and operations for tactical aircraft are reflected herein. The basic source of the post-1985 mission requirements is the TAC-85[1] study. Because it was conducted by USAF Headquarters in 1970, it needed a review and some updating.

Mission Model

The mission model describes the operational requirements and performance characteristics for tactical aircraft operating after 1985. The primary operational environment is Central Europe during a major NATO/Warsaw Pact engagement. The performance descriptions emphasize the areas which will influence aircrew functions and interface with the aircraft.

Mission Requirements

Mission requirements are defined for an aircraft performing deep strike, battlefield interdiction and close air support missions. The general characteristics of the mission are compared in Table 1. Mission profiles for each mission are described.

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[1] "Air Force Tactical Forces 1985 Study (U)," Final Report, HQ TAC, Langley AFB, Virginia, May, 1971, Secret.

TABLE 1. MISSION COMPARISONS

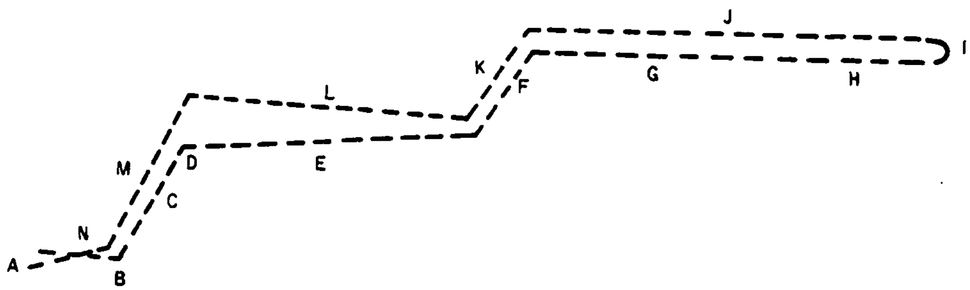
Missions	Targets	Threat	Typical Weather	Response Time	Flight Profile	Typical Weapons
Deep Strike	Airfields Transport Facilities	Intercepters SAMS, AAA	Low Clouds Haze	1-2 Days	Hi-Super- sonic	SOM GBU-15 SAR/SARG
Battlefield Interdiction	Armor SAMS Supplies	SAMS AAA	Low Clouds Haze	1/2 Hour	Lo/Lo Subsonic	GBU-15 SAR/SARG Maverick Guns/Bombs Mini-Missile
Close Air Support	Armor Troops Fortifica- tions	Tactical SAM AAA	Low Clouds Haze	1/2 Hour	Lo/Lo Subsonic	Maverick Guns/Bombs LGB

Deep-Strike Mission Profile

Deep-strike missions attack airfields, surveillance and GCI radars, Command, Control and Communication facilities, and high-value transportation and supply targets. There are several essential operational characteristics and requirements for these missions:

- Targets are at a known geographical position
- Imagery for the targets is available
- Targets are fixed or will remain in place for a period of days
- Threats to the mission have a significant impact on flight profiles and on the allowable time within the threat zones of operation. This is reflected in altitude and air-speed profiles, and in the operation of threat-warning and threat-avoidance systems
- Weather conditions include a low cloud cover and limited visibility. During the winter, the average visibility is low and the average cloud ceilings are 2000 feet
- High sortie rates are required to rapidly reduce the effectiveness of enemy forces. This, in turn, imposes the need for an all-weather and day/night capability

The deep-strike mission profile is shown as a series of segmented functions in Figure 1. The individual segments and the primary functions are described in the figure.



MISSION PHASE		FUNCTIONS
A	PRE TAKE-OFF	A/C EQUIPMENT STARTS, TEST AND CHECKOUT, REFUEL AND RELOAD
B	TAKE-OFF AND ACCELERATE TO OPTIMUM CLIMB	A/C CONTROL, VISUAL OBSTRUCTION, TRAFFIC COORDINATION
C	CLIMB TO CRUISE ALTITUDE-- USE 30,000 FT.	A/C CONTROL, NAVIGATION, TRAFFIC COORDINATION
D	RENDEZCOUS WITH OTHER AIRCRAFT ONMISSION	A/C CONTROL, VISUAL/SENSOR SEARCH, MISSION COORDINATION
E	CRUISE AT M 0.9 FOR 200 nmi	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE
F	CLIMB TO DASH ALTITUDE: 60,000 FT.	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE
G	HIGH SPEED INGRESS AT M = 2.0 FOR 200 nmi	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE
H	TARGET SEARCH USING SAR	A/C CONTROL, NAVIGATION, COORD. ATTACK, THREAT SURVEILLANCE, SAR DATA PROCESSING, TARGET IDENTIFICATION AND TRACK
I	WEAPON DELIVERY USING BOOST/GLIDE ROCKET	A/C CONTROL, DESIGNATE TARGET, LAUNCH ROCKET, THREAT EVALUATION, THREAT DESIGNATION, LAUNCH ARMAMENT, TARGET TRACK BOMB DAMAGE ASSESSMENT, COORDINATE ATTACK
J	HIGH SPEED WITHDRAWAL AT M 2.0 FOR 200 nmi	A/C CONTROL, NAVIGATION, THREAT SURVEILLANCE, FORMATION FLYING
K	DESCEND TO CRUISE ALTITUDE	A/C CONTROL, NAVIGATION, THREAT SURVEILLANCE, FORMATION FLYING
L	CRUISE AT M 0.9 FOR 200 nmi	A/C CONTROL, NAVIGATION, THREAT SURVEILLANCE, FORMATION FLYING
M	DESCEND TO AIRFIELD	A/C CONTROL, NAVIGATION, TRAFFIC COORDINATION
N	LAND	A/C CONTROL, VISUAL OBSTRUCTION, TRAFFIC COORDINATION, LANDING AID OPERATION

Figure 1. Deep Strike Mission Profile

The mission profile is based on the following assumptions:

- The aircraft is part of a coordinated mission using several aircraft
- Synthetic aperture radar is used as a long-range ground search sensor
- Synthetic aperture retransmissicn guidance (SARG) missile is used for the target attack

A flight profile for the mission is shown in Figure 2. A time profile for the mission is shown in Figure 3.

Alternative sensor and weapon combinations for this mission are as follows:

- GPS-controlled launch point (GBU-15 weapon and FLIR sensor with data link)
- Inertial navigation-controlled launch point (SOM with TERCOM)

Battlefield Interdiction Mission Profile

Battlefield interdiction missions are against weapons, personnel, transportation and supplies of the enemy's ground forces. The essential operational characteristics and requirements for this mission are as follows:

- Targets are identified by aerial reconnaissance and surveillance sensors and are at a known location

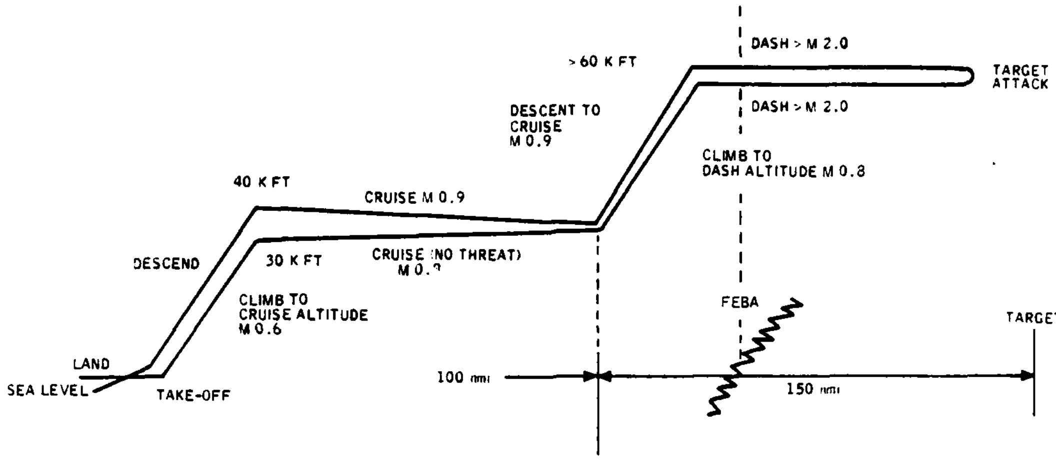


Figure 2. Deep Strike Mission Flight Profile

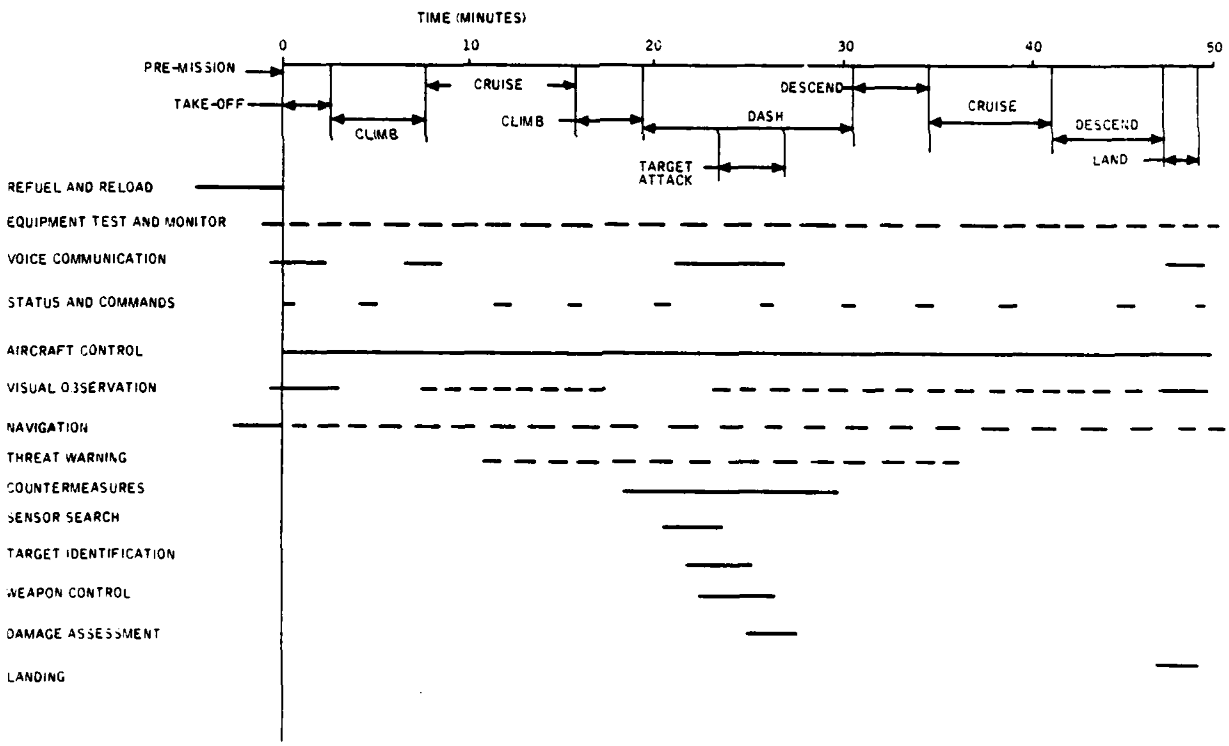
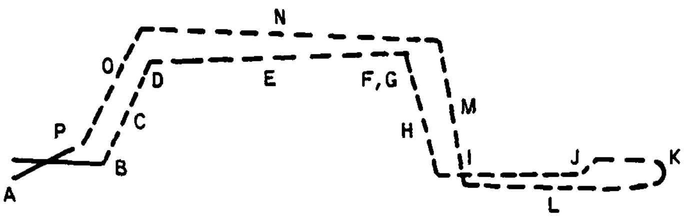


Figure 3. Deep Strike Mission Time Profile

- There is no imagery for the target
- Targets are mobile or highly transient
- Weather and viewing conditions limit the usefulness of visual operations. Day/night and all-weather sensors and weapons are needed to meet the requirements for many of the sorties
- High sortie rates are required to deal with the large number of targets
- Time of flight to the target area must be minimized because of the transience of the target
- Threat to the mission includes the tactical SAMS and AA Guns that can operate against the very low altitude, high-speed mission profile. This includes SA6, SA8, and ZSU-23-4

The battlefield interdiction mission profile, is shown as a series of segments in Figure 4. Individual segments are described and the primary functions listed in the figure. The mission profile is based on the following assumptions:

- The aircraft is part of a coordinated mission using several aircraft
- Forward-looking infrared (FLIR) is used for a ground search sensor
- Imaging IR (IIR) Maverick is used for attacking the target



MISSION PHASE	FUNCTIONS
A PRE TAKE-OFF	A/C EQUIPMENT STARTS, TEST AND CHECKOUT, REFUEL AND RELOAD
B TAKE-OFF AND ACCELERATE TO CLIMB	A/C CONTROL, VISUAL OVSERVATION, TRAFFIC COORDINATION
C CLIMB TO CRUISE ALTITUDE-- 30K FT	A/C CONTROL, NAVIGATION, TRAFFIC COORDINATION
D RENDEZVOUS WITH OTHER AIRCRACT ON MISSION	A/C CONTROL, VISUAL/SENSOR SEARCH, MISSION COORDINATION
E CRUISE AT M 0.9 FOR 200 nmi	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE
F RENDEZVOUS WITH TANKER	A/C CONTROL, VISUAL/SENSOR SEARCH, MISSION COORDINATION, THREAT SURVEILLANCE
G REFUEL	A/C CONTROL, FUEL TRANSFER, MISSION COORDINATION, THREAT SURVEILLANCE
H DESCEND, LOITER AT MINIMUM POWER FOR 15 MIN	A/C CONTROL, NAVIGATION, MISSION COORDINATION, THREAT SURVEILLANCE
I HIGH SPEED PENETRATION M 1.2 AT 100 FT ALTITUDE FOR 50 nmi	A/C CONTROL, NAVIGATION, MISSION COORDINATION, TERRAIN AVOIDANCE, THREAT SURVEILLANCE, ECM OPERATION, VISUAL/SENSOR SEARCH
J TARGET SEARCH USING FLIR, POP-UP TO SEARCH ALTITUDE	A/C CONTROL, FLIR SEARCH, TARGET IDENTIFICATION AND TRACK, THREAT SURVEILLANCE, ECM AND DECOY OPERATIONS, MISSION COORDINATION
K WEAPON DELIVERY USING IIR MAVERICK	A/C CONTROL, WEAPON LOCK-ON, WEAPON LAUNCH, THREAT SURVEILLANCE, ECM AND DECOY OPERATIONS, MISSION COORDINATION, DAMAGE ASSESSMENT
L HIGH SPEED WITHDRAWAL	SAME AS I
M CLIMB TO CRUISE ALTITUDE	SAME AS H
N CRUISE TO BASE AREA	SAME AS E
O DESCEND TO AIRFIELD	SAME AS C
P LAND	A/C CONTROL, VISUAL/SENSOR SEARCH, TRAFFIC COORDINATION, LANDING AID OPERATION

Figure 4. Battlefield Interdiction Mission Profile

A flight profile for the mission is presented in Figure 5, and time profile is presented in Figure 6.

Alternative sensors and weapons for this mission include:

- Visual identification of the target; CBU delivery using CCIP fire control in a laydown mode

- SLAR identification of the target; with GBU-15 delivery of minimissile submunitions

Close-Air-Support Mission Profile

Close air support missions are conducted at the request of the tactical ground forces' commander. A ground- or air-based forward air controller coordinates the air attack with the ground forces by designating the target position and by controlling the air-support mission during the attack phase. The targets include enemy weapons, troops, fortifications, and transports that are an immediate threat to the mission of the ground forces.

The essential operational characteristics and requirements for this mission are as follows:

- Targets are generally mobile, and may be moving
- Targets have been located by the tactical ground forces and are identified by position or by a designator operated by the forward air controller

- An ability to strike the target on a few minutes notice is needed

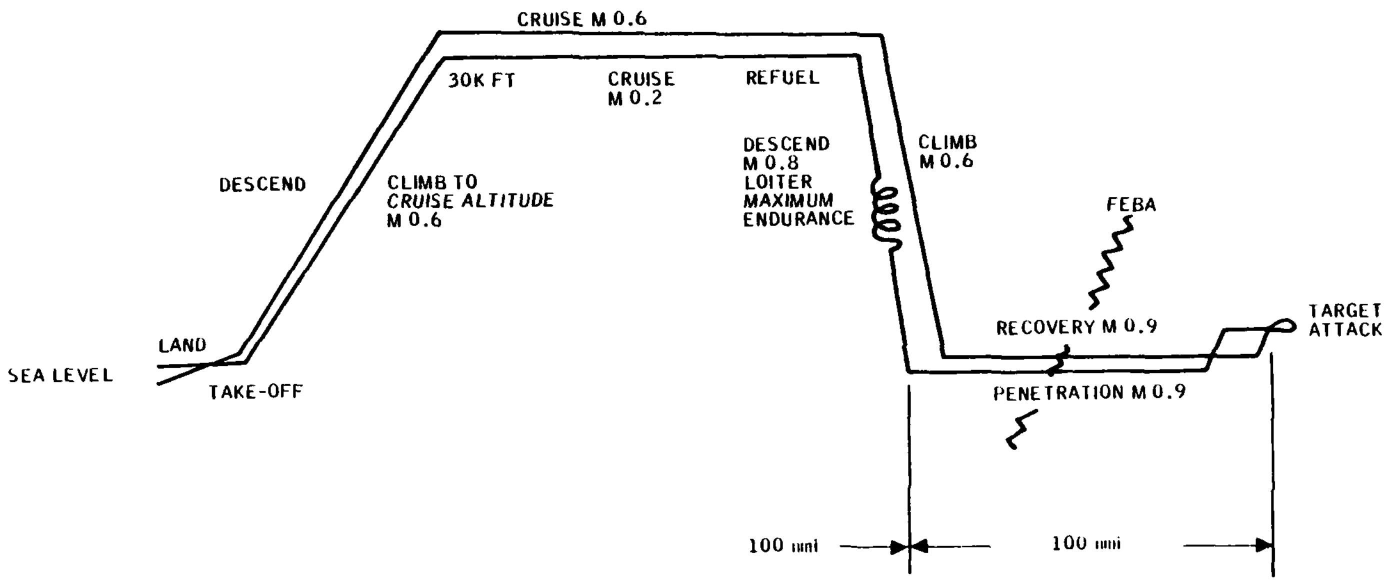


Figure 5. Battlefield Interdiction Mission Flight Profile

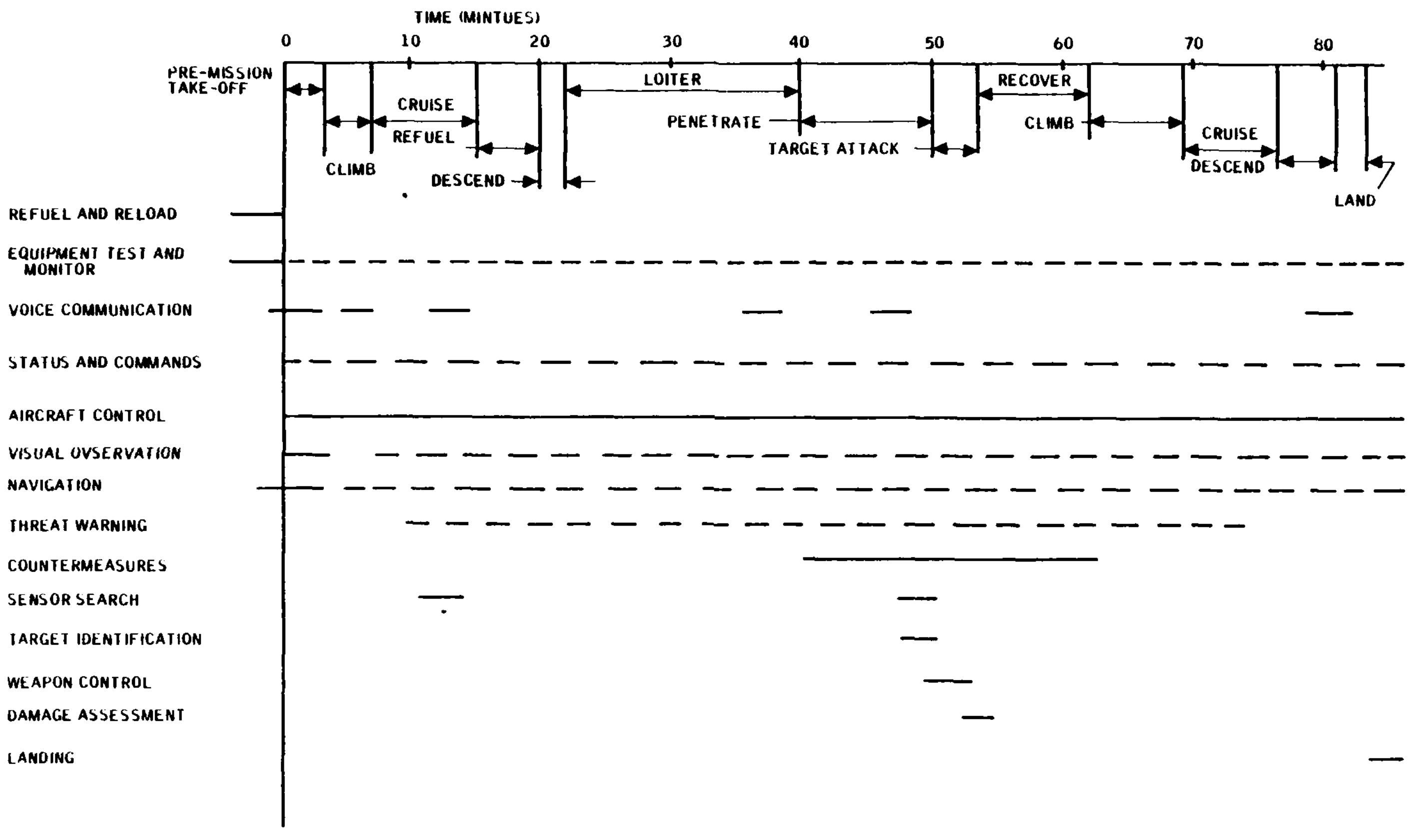


Figure 6. Battlefield Interdiction Mission Time Profile

- Threat to the mission will be primarily the SA-8, SA-9 and ZSU-23-4 weapons that are operating within the attacking units

- The aircraft must be able to remain on airborne station and to make a series of target attacks from the station as needed

- Weather conditions will include low clouds and limited visibility

The close-air-support mission profile is shown as a series of segments in Figure 7. The individual segments and the primary functions are described in the figure.

The mission profile is based on the following assumptions:

- The aircraft is part of a coordinated mission using several aircraft

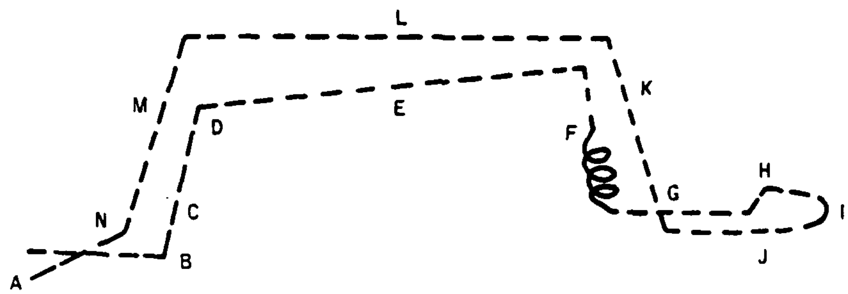
- The target is identified by the FAC using a laser designator

- Laser Maverick is used to attack the target

A typical flight profile for the mission is shown in Figure 8. A time profile is shown in Figure 9.

Alternative sensor and weapon combinations are as follows:

- Visual identification of the target; 30-mm gun attack



MISSION PHASE	FUNCTIONS
A PRE TAKE-OFF	A/C EQUIPMENT STARTS, TEST AND CHECKOUT, REFUEL AND RELOAD
B TAKE-OFF AND ACCELERATE TO CLIMB	A/C CONTROL, VISUAL OBSERVATION, TRAFFIC COORDINATION
C CLIMB TO CRUISE ALTITUDE--25K ft	A/C CONTROL, NAVIGATION, TRAFFIC COORDINATION
D RENDEZVOUS WITH OTHER AIRCRAFT ON MISSION	A/C CONTROL, VISUAL/SENSOR SEARCH, MISSION COORDINATION
E CRUISE AT M 0.7 FOR 100 nmi	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE
F DESCEND AND LOITER AT MINIMUM POWER FOR 15 MIN	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE, COORDINATION WITH FAC
G PENETRATE TO FEBA	A/C CONTROL, NAVIGATION, FORMATION FLYING, THREAT SURVEILLANCE, COORDINATION WITH FAC
H TARGET SEARCH LASER DETECTOR	A/C CONTROL, THREAT SURVEILLANCE, LASER SEARCH AND TRACK, COORDINATION WITH FAC, ECM OPERATION
I WEAPON DELIVERY USING LASER MAVERICK	A/C CONTROL, WEAPON LOCK-ON AND LAUNCH, THREAT SURVEILLANCE, ECM OPERATION
J WITHDRAWAL TO LOITER POSITION, REPEAT ATTACK PROCESS AS NEEDED	SAME AS F
K CLIMB TO CRUISE ALTITUDE	SAME AS F
L CRUISE TO BASE AREA	SAME AS E
M DESCEND TO AIRFIELD	SAME AS C
N LAND	A/C CONTROL, VISUAL/SENSOR TRAFFIC COORDINATION, LANDING AND OPERATION

Figure 7. Close-Air Support Mission Profile

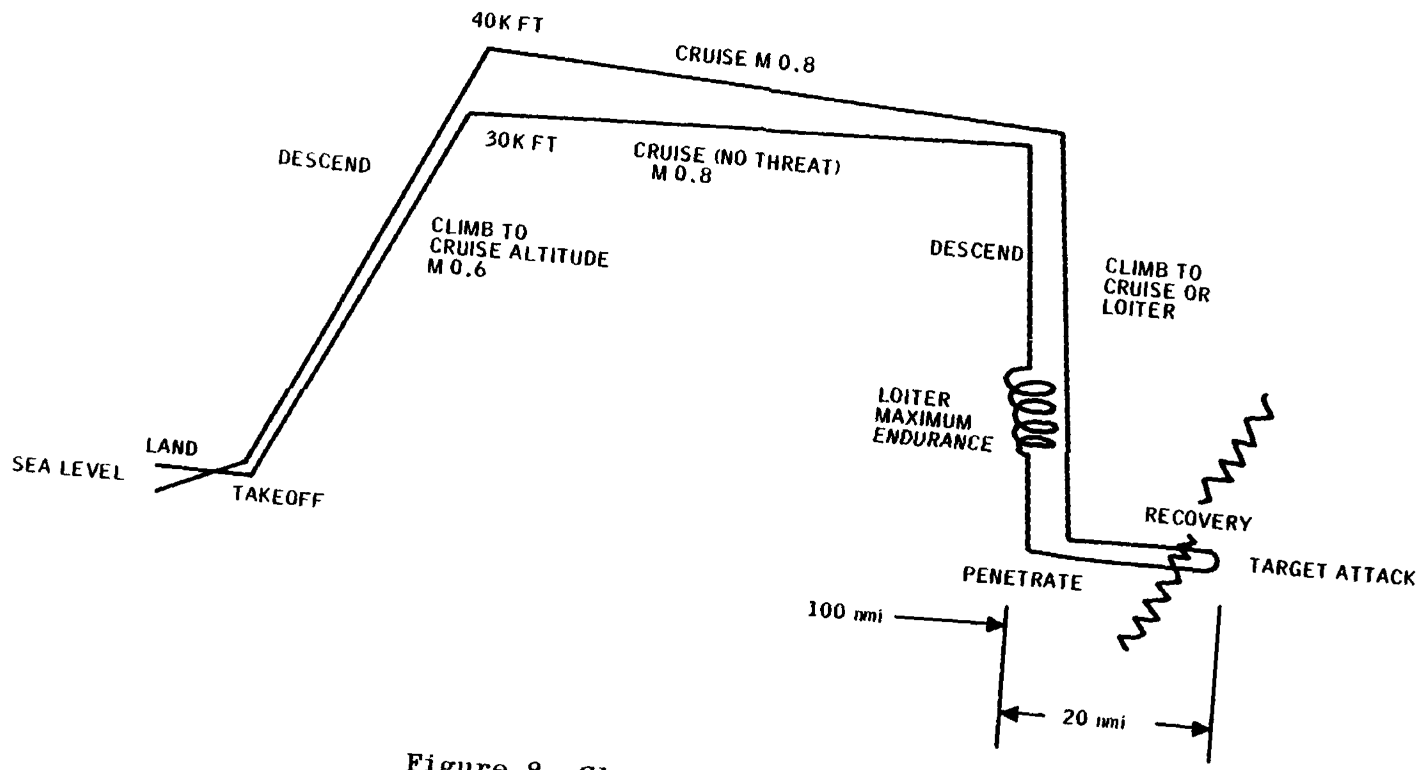


Figure 8. Close-Air Support Mission
Flight Profile

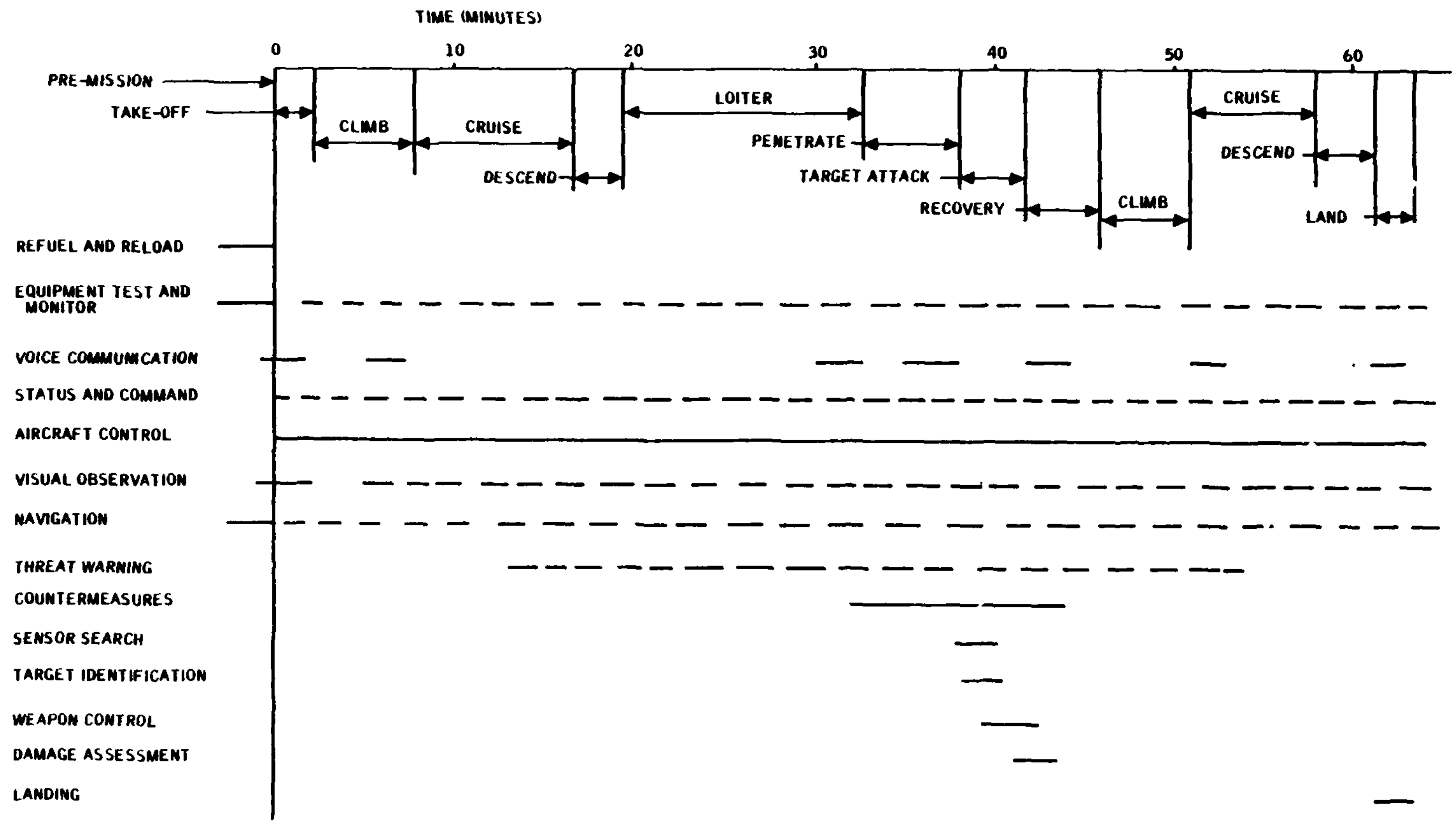


Figure 9. Close-Air Support Mission Time Frofile

- Launch relative to FAC controlled beacons; inertially guided GBU-15 with sensor fuzed submunitions

Threats

To support the need for high-speed, low-level intrusion's flights, Figure 10 shows the typical radar coverage of three missile sites for three aircraft altitudes. The immediate site is a system set up within 5 minutes of a roadway. The expedient site is within 30 minutes of a roadway and the pre-planned site was selected for its excellent coverage. The light areas represent the segments where the aircraft is exposed to tracking by the radar site. Slow flying aircraft at 1000 feet over a preplanned site may experience a 50 times increase in radar tracking exposure as compared to high-speed aircraft at 250 feet over immediate sites.

WEAPONS

This section reviews a wide range of air-to-ground weapons which may interact with multisensor displays. The actual selection of weapons in subsequent tasks will depend on the type of target and its value, the threat to the aircraft, and the weather conditions. Information used to define the operational functions for the current weapons and the aircrew's interface with them has been obtained from flight manuals, equipment tech orders and from weapons specifications. Information on the advanced weapons was obtained from reports on design studies on specific weapons and from the TAC-85 study. The weapons appropriate for after 1985 include most of the current inventory of weapons, and many weapons that are in

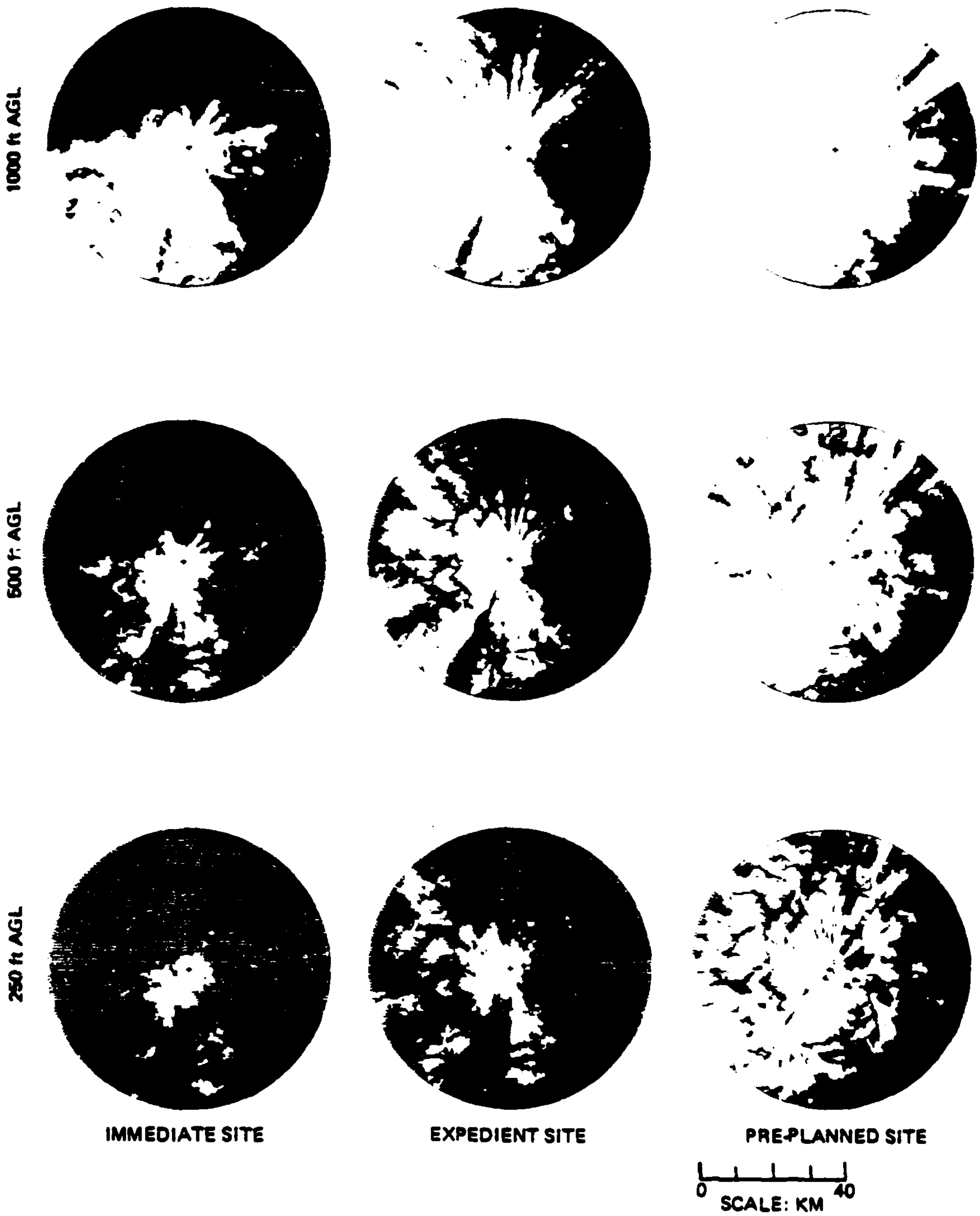


Figure 10. Intervisibility Map for Threat Sites

various phases of development. The current inventory includes a wide variety of unguided bombs and rockets, the Pave Way and Pave Strike program developments, the Maverick family, the ARM weapons, and gun systems. Programs in the developmental process include the stand-off missile (SOM) and improved ARM, improved guidance using radio-navigation techniques and sensor data-correlation techniques; and all-weather sensor/trackers.

Weapons Categorization

A broad selection of weapons was made from this total so that most of the possibilities are represented. The general characteristics of the initial selection of weapons are outlined in Table 2. The weapon interface with the aircraft and crew is outlined in Table 3. The weapons are organized in functional groups having similar characteristics in terms of the aircrew and aircraft interfaces:

- Unguided Weapons. These weapons require the aircrew to visually acquire the target and to use the aircraft fire control system to obtain the correct conditions for launching weapons

- Lock-On-Before-Launch Weapons. These weapons require the aircrew to visually, or through sensors, acquire the target; to lock the weapon seeker onto the target; and to launch the weapon

TABLE 2. INITIAL WEAPON SELECTION

WEAPON	GUIDANCE TECHNIQUE	WEATHER LIMITS	TARGETS	RANGE, (STANDOFF)	DELIVERY TECHNIQUE
UNGUIDED					
GP Bomb	Unguided	Visual	Area; Unarmored	1K to 10K Ft.	Level, dive, loft
CBU; Rockeye	Unguided	Visual	All Tactical	1K to 10K Ft.	Level, dive, loft
FAE	Unguided	Visual	Area; Unarmored	1K to 10K Ft.	Level, dive, loft
Snakeye	Unguided	Visual	Area; Unarmored	200 to 2000 Ft.	Level
30MM Cannon	Unguided	Visual	All Tactical	1K to 10K Ft.	Dive
LOCK-ON BEFORE LAUNCH					
KMU-353 (Hobo)	EO Tracker	Visual	All Tactical	To 12nmi.	Dive
Maverick					
AGM 65A	EO Tracker	Visual	All Tactical	0.5 to 7 mi.	Dive
AGM 65B	EO Tracker	Visual	All Tactical	0.5 to 12 mi.	Dive
AGM 65C	Laser Tracker	Day/Night	All Tactical	0.5 to 12 mi.	Dive
AGM 65D	FLIR Tracker	Day/Night	All Tactical	0.5 to 12 mi.	Dive
Night Maverick	FLIR Tracker	Day/Night	All Tactical	0.5 to 12 mi.	Dive
LOCK-ON AFTER LAUNCH					
GBU-15	EO-Data Link	Day	All Tactical	20 nmi.	Level
	FLIR - Data Link	Day/Night	All Tactical	20 nmi.	Level
AUTONOMOUS AFTER LAUNCH					
GBU-15	TOA-DME	All Weather	Emitters	30 nmi.	Level
	TERCOM, MICRAD	All Weather	Fixed	30 nmi.	Level
	GPS, JTID	All Weather	Fixed	30 nmi.	Level
	MMWAVE Submuni.	All Weather	Armor	20 nmi.	Level
SOM	TERCOM, MICRAD	All Weather	Fixed	200 nmi.	Level
	LCIGS+ED CORR.	Day/Night	Fixed	200 nmi	Level
Paveway	Laser Tracker	Day/Night	All Tactical	5 nmi.	Level
Shrike, Harm	Radar Tracker	All Weather	AA Radars	10 mi.	Level
Standard Arm	Radar Tracker	All Weather	AA Radars	15 mi.	Level

TABLE 3. PRELIMINARY WEAPON/AIRCRAFT/CREW INTERFACE

WEAPON	BASIC CREW FUNCTION	AIRCRAFT EQUIPMENT	CREW/WEAPON INTERFACES
UNGUIDED			
GP Bomb	Visual Search/Acq; A/C Control for Launch	Fire Control (CCIP); Laser Ranger; HUD; Launch Control	Equipment Controls, Fire Control Display (on HUD), Status Displays
Rockeye, CBU	"	"	"
FAE	"	"	"
Snakeye	"	"	"
30 MM Cannon	"	"	"
LOCK-ON BEFORE LAUNCH			
KMU-353 (Hobo)	Visual Search & Acq; A/C Control for Lock-On; Seeker Lock-On	Fire Control; Ranger; Optical sight; Sensor Display; Launch Control	Equipment Controls, Optical Sight, Seeker Video Display, Status Display
Maverick AGM-65A, B, D	"	"	"
AGM 65C, and Night Maverick	FLIR Search, Acq.; Lock-On; Seeker Lock-On, A/C Control for Launch	Fire Control; Pave Tack POD; Sensor Display; Launch Control	Equipment Controls, Fire Control Display, FLIR Video Display, Status Displays
LOCK-ON AFTER LAUNCH			
GBU-15 (TV-DL) 4 SOM (TV-DL)	Navigation and A/C Control for Launch; EO Seeker Search, Acq., Lock-on.	Nav. System, Fire Control Sys., Launch Control, Data Link; Sensor Display, Weap. Control	Equipment Controls, Navigation Display, Launch Control, Seeker Video Display, Status Display, Weapon Control
AUTONOMOUS			
GBU-15 (TOA-DME)	Navigation and A/C Control for Launch	DMG Receiver, Nav. System, Fire Control Sys., Launch Cont.	Equipment Controls, Navigation Display, Launch Control
- TERCOM, MICRAD	"	Nav. Sys., Fire Cont., Launch Cont.	"
- GPS, JTIDS, LCIGS	"	Radio-Nav. Receiver, Nav. Sys., Fire Control Sys., Launch Control	"
SOM	"	"	"
Paveway	Visual or Laser Search and Acq., A/C Control For Launch	Fire Control, Ranger, Optical Sight, Launch Control	Equip. Controls, Fire Control Display, Status Display.
Shrike, Harm,	Evaluate Threat Data;	Fire Control; ECM and Display;	Equipment Controls, Fire Controls
Standard Arm	Seeker Lock-On; A/C Control for Launch	Launch Control	Display, ECM Display, Status Display

- <u>Lock-On-After-Launch Weapons</u>. These weapons require the aircrew to navigate to a known position and to launch the weapon toward the target; to control the weapon seeker so as to obtain the target area imagery via the data link; to identify the target in the imagery and to control the seeker to lock onto the target

- <u>Autonomous Weapons</u>. These weapons require the aircrew to navigate to a position relative to the target and to launch the weapon toward the target.

Unguided Weapons

The unguided weapons are the general choice when the anti-aircraft threat is small. Using the advanced bombing systems-CCIP (Continuously Computed Impact Point) and ARBS (Angle Rate Bombing System) very good weapon delivery accuracy is obtained.

With release at short range, and using an appropriate warhead, good effectiveness is obtained against most of the tactical targets. The unguided weapons listed in Tables 2 and 3 included the following:

- General-purpose bombs -- Effective against all of the tactical targets except the small, hard targets which require a direct hit

- Cluster bomb units -- Alternative submunitions and effective against the total range of tactical targets. Both area targets and point targets can be attacked by controlling the submunition pattern. Sensor-fuzed busmunitions are good against concentrations of armor

- Fuel air explosives -- Fuel-air-explosive (FAE) devices are particularly effective against area targets that are vulnerable to overpressure

- Snakeye -- This is representative of the retarded weapons designed for launching at very low altitudes

- 30-mm Cannon -- This weapon represents the short-range, boosted category, which includes both rockets and cannons. The cannon is effective against the small, hard target when used at short range. The development of a flexible gun will improve the attack options

External factors influence the effectiveness of the aircrew: search area, search time and conspicuousness of the target. In general, the aircrew should have a minimum of distractions when conducting a search; the transition from search to attack should require a minimum of time; and the pilot should have no distractions while delivering the weapon.

Lock-On-Before-Launch

The lock-on-before-launch weapons include Maverick, HOBO, and one of the GBU-15 configurations. These weapons have been used very effectively in Vietnam, primarily to destroy bridges; and in the Arab-Israeli conflicts to destory tanks. They provide both a longer stand-off and a better terminal accuracy than the unguided weapons.

They require the aircrew to visually acquire the target by ground search and/or by search of sensor video data. The target must be designated in the sensor video such that the weapon sensor will start tracking the target. With weapon tracking established, it can be launched as soon as the aircraft is within the launch envelope.

External factors also influence the aircrew's effectiveness: Search area, search time, and conspicuousness of the target. In general, the aircrew should have a minimum of distractions during the target search operation; and the transition from search to seeker lock-on should occur in as little time as possible.

Lock-On-After-Launch

The lock-on-after-launch weapons include Condor and one of the GBU-15 and SOM configurations. These weapons are being developed and have a critical vulnerability to ECM because they need a high data rate (video) data link. They will be very useful against high-value, highly defended, stationary (for several hours) targets.

Operating in a relatively safe area, the aircrew navigates to a preselected launch point and maneuvers to align the weapon's inertial system and to obtain the needed launch conditions. As the weapon approaches check points, or approaches the target area, the data link must be activated to control the weapon's sensor search and to obtain the sensed data. The check point or target is identified in the displayed sensor data and is designated to the weapon sensor. Depending on the stage of the mission, either the navigation errors are corrected, or terminal homing is initiated.

The external factors which influence the aircrew's effectiveness are weather, targeting accuracy, target conspicuousness, and data link link countermeasures. The weapon-system factors are search data, search time, and sensor definition of the ground scene.

As general guidelines, the aircrew should have a minimum of distractions during the target search, and the transition from search, to lock-on, to terminal flight should require a minimum amount of time.

Autonomous Weapons

The autonomous weapons have a mix of functions, including defense suppression, stand-off deep strikes, and close air support. In common, they relieve the aircrew of searching for the target. The weapons include most of the GBU-15 and SOM configurations, the laser-guided weapons and the ARM weapons.

The laser-guided weapons require that the target be illuminated by a laser designator. This requires a search and acquisition process, but will be conducted by an FAC or other aircraft in the mission. Both the laser-guided weapon and the ARM weapon may detect the target prior to launching and may provide information for fire control and weapon launch. The GBU-15 and SOM require that the aircrew navigate to a launching position in a safe area. Maneuvers then occur to align the weapon's inertial navigation systems and to obtain the desired launching conditions.

Conclusions of Mission and Weapon Analyses

A preliminary evaluation of mission profiles and weapon systems suggested that the current multisensor concepts apply and offer major benefits for the battlefield interdiction mission, and the close air support mission. They may also aid in controlling unguided weapons, and some lock-on-before-launch weapons. However, the evaluation also indicated that the concepts may be expanded to cover lock-on-after-launch systems containing a video link. In addition, the concepts require an expansion to cover three and four sensors.

SECTION 3
DEFINITION OF SENSOR CHARACTERISTICS

To better understand the potential advantages of combined sensor display and to generate effective concepts for combining sensor inputs on a single display, it was necessary to review the characteristics of the individual sensors. For the particular aircraft and missions of interest, FLIR and radar were the most promising candidates. Each of these sensors operates in a different mode, responds to different properties within the field of view, and (in traditional displays) presents this information to the operator in different formats. The following paragraphs summarize some of the more important properties of these two sensors. The end of this section discusses the function of a "second sensor."

35-GHz RADAR

Detection and surveillance of ground targets require a system of high angular resolution. High-resolution radars demand a small beamwidth or large aperture antennas. In a high-performance aircraft, the antenna size is usually limited to the available areas in the nose or an externally attached radar pod.

Since the effective antenna aperture is inversely proportional to frequency, millimeter waves ($f > 30$ GHz) offer the following:

- Superior angular resolution for a given antenna physical size

- More nearly covert operation (low probability of intercept)

- Lower susceptibility to jamming

Millimeter wave (MMW) radars, however, are susceptible to such environmental factors as rainfall attenuation, which reduces the overall effective range. These factors must be carefully evaluated to predict the MMW radar detection range.

As an example, an environmental diagram was designed to illustrate the detection ranges of reasonable size antennas (12", 8", 6") at 35 GHz. This hypothetical system can readily be modified by changing some radar parameters (such as transmitter power, target size, etc.) to predict performances in clear weather and inclement weather. In comparing 35 GHz and 94 GHz, 94 GHz has the clear advantage in angular resolution, but has a significantly higher rainfall-attenuation characteristic.

Figures 11 and 12 are read by selecting the target size (cross section) on the bottom scale and going up to the antenna/frequency lines. At this intersection, the range is read out in km on the right-hand scale. To find the range due to weather attenuation, the range on the right-hand scale is traced back across the graph to the appropriate attenuation curve near the left. At this intersection, the range reduction due to precipitation attenuation is shown in km on the top scale.

For surveillance, a MMW system could be designed with a reasonable angular resolution (say about 1-2 degrees) at antenna scan rates up to 120°/sec. To ensure adequate surveillance, the following factors must be considered:

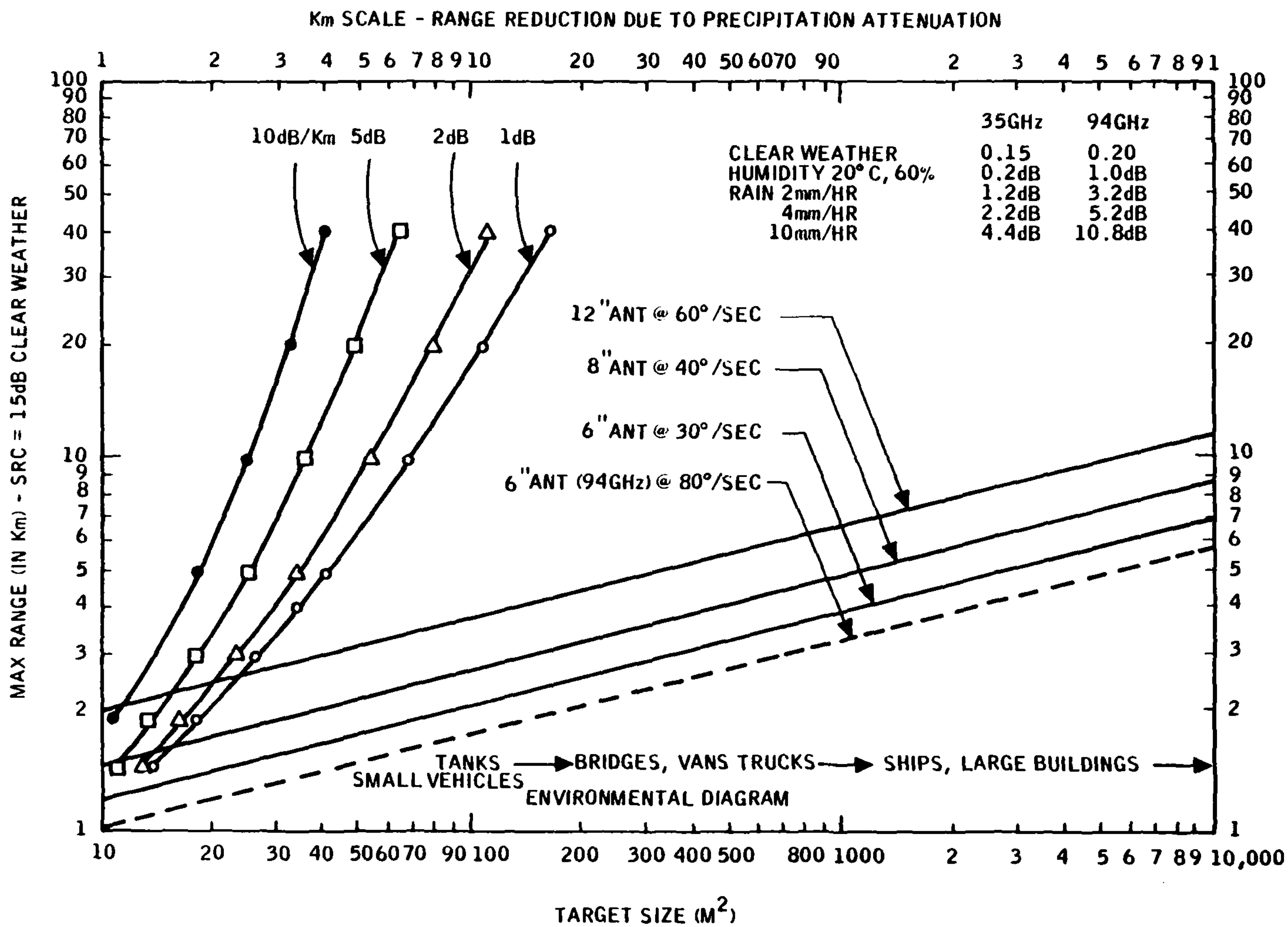


Figure 11. Environmental Diagram: Large Antennae

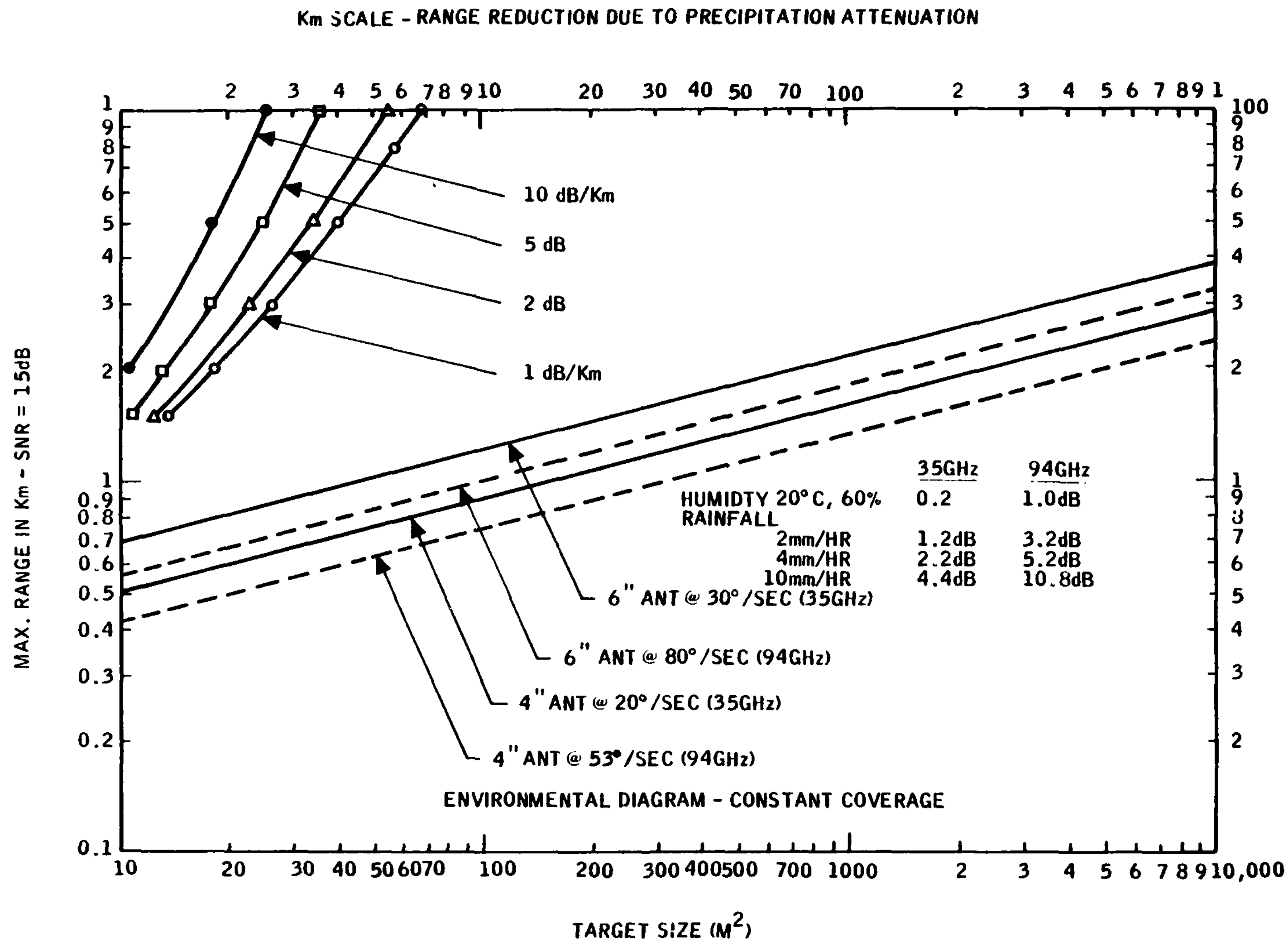


Figure 12. Environmental Diagram: Small Antennae

(1) Aircraft velocity and altitude

(2) Antenna beamwidth and scan rates

For detecting light to moderate rainfall, ranges of 3-7 km can be achieved with the hypothetical MMW radar. The radar outputs would be azimuth and elevation (relative to the gimbled platform), and range. Angular accuracies on the order of 1-2 milliradians and range accuracies of about 50 feet can be expected. The antenna could be scanned in both axes, or use a fixed depression angle and scanned in azimuth.

DUAL-MODE RADAR

The three-watt, 35-GHz radar system discussed has a small antenna, high resolution and low susceptibility to jamming. However, as shown in Figure 13, the 35-GHz system's performance deteriorates rapidly in poor weather.

To overcome these limitations, a second, dual-mode, air-to-ground system was considered for high-performance attack aircraft. This radar, with an IR and/or EO sensor, provides the pilot with a multispectral display of the target area. For navigating, the radar also displays terrain features extending above the aircraft's altitude.

The transmitter is a 10-watt pulsed Impatt diode employing a spread spectrum centered at 16 GHz. The pulse-width is 200ns with a 25-MHz chirp bandwidth. Frequencies higher than 16 GHz are considered impractical for this application due to the high rain clutter and rain attenuation encountered in the terrain-avoidance mode. Lower frequencies do not provide the required angular resolution.

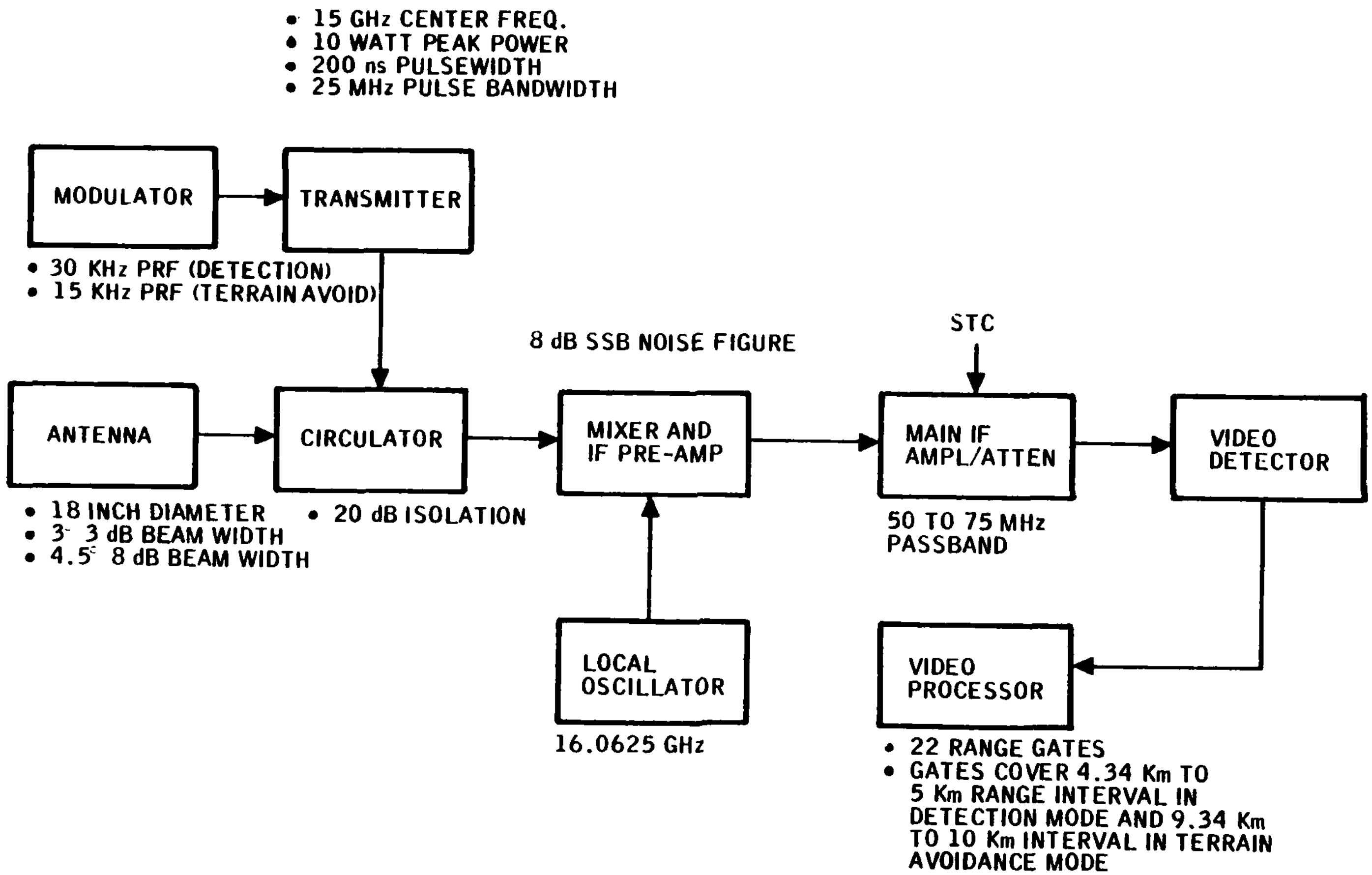


Figure 13. Functional Block Diagram of the Dual Mode 16-GHz Radar System

In a rainfall of 4 mm/hr, an operating range of 5 km is achievable in the target-detection mode, and 10 km in the terrain-avoidance mode. The two modes are time-shared, with detection performed on the left to the right scan at a 1.75 degree depression angle, and the terrain mapping on the returning right-to-left scan at a -1.5 degree depression angle.

Terrain avoidance and the detection of ground targets are both air-to-ground functions and impose similar requirements on the radar sensor. Therefore, a single radar can accomplish both functions. However, the radar antenna must be tilted above the horizon to perform the terrain-avoidance function, and below the horizon to detect targets. Thus, two time-shared modes of operation are required.

A functional block diagram of the proposed design is presented in Figure 13. The RD and IF (Intermediate Frequency) processing are identical for the two modes, except for the pulse repetition frequency (PRF), which is defined as:

$$PRF = \frac{C}{2\ R_{unamb}},$$

where

C = speed of light and

R_{unamb} = maximum unambiguous range (i.e., echoes correspond to previously transmitted pulse).

The 5-km maximum operating range in the detection mode permits a maximum PRF of 30 kHz. A 15-kHz PRF is employed in the terrain avoidance mode, which has a 10 km operating range.

The video processor has 22 contiguous range gates, each matched to the 200 ns-transmitted pulsewidth. In the detection mode, these gates are implemented to cover the 660m ground swath from 4.34 to 5 km. The 660m coverage is necessary, since the aircraft moves approximately this distance (800 fps) during the full 2.66-sec antenna-scan period. This scan period assumes a minimum gimbal scan rate of 60°/sec and a $\pm 45^{\circ}$ field of view. The detection mode occurs on the left-to-right scan and the terrain avoidance on the returning right-to-left scan. If a wider ground coverage is desired for mapping, more range gates can be implemented. However, as indicated in Figure 14, the maximum range swath is limited to the interval from 2.7 to 5 km due to antenna illumination. (Note that a depression angle of 1.75 degree is required to maximize antenna gain for targets at the 5 km range.

In the terrain-avoidance mode, the 22 gates are implemented to cover the 660m ground swath from 9.34 to 10 km. As illustrated in Figure 15, the antenna is tilted upwards at 1.5°. The antenna gain seen by flat terrain at a range of 10 km is 8 dB below the mainlobe gain, which is viewing terrain above the aircraft's line of flight. Therefore, the undesired signal returns from terrain below the aircraft's altitude will be at least 16 dB (two-way antenna gain difference) lower than the desired signal returns from terrain above the aircraft's altitude. An adaptive threshold can easily be implemented which will ensure that the radar responds only to the desired higher altitude terrain returns. A sensitivity time control (STC) function must also be implemented to remove the effect of range on received signal level.

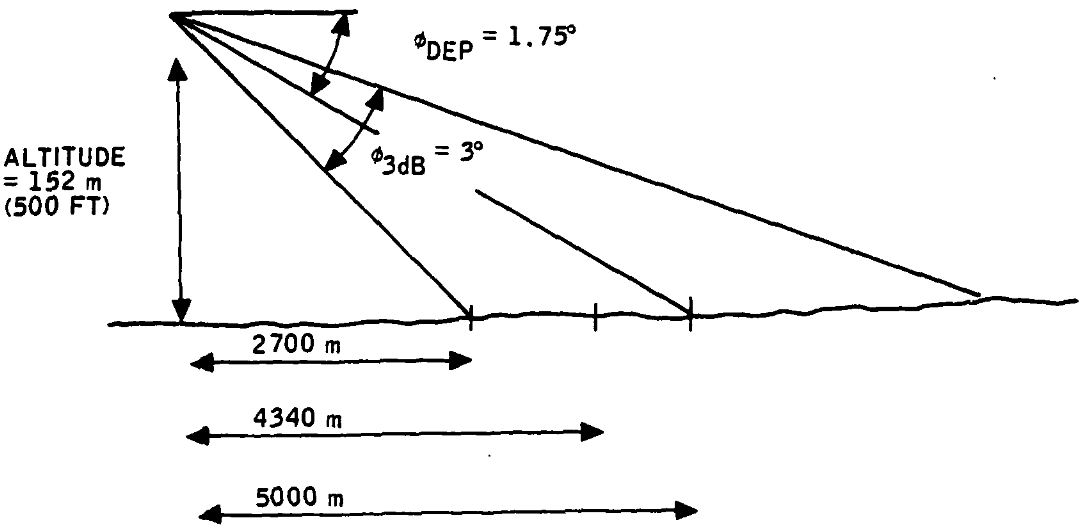


Figure 14. Target Detection Geometry

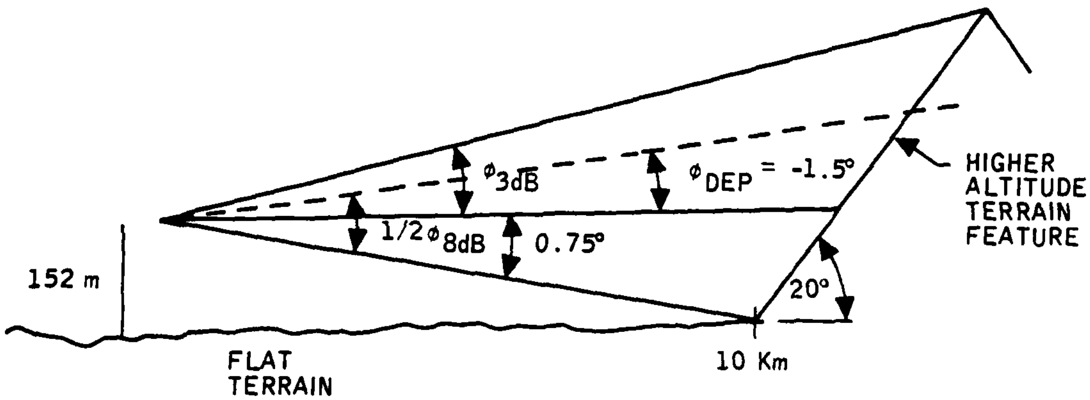


Figure 15. Terrain Avoidance Geometry

Preliminary calculations indicate that, at the maximum operational ranges, the signal-to-noise ratio (SNR) and the signal-to-clutter ratio (SCR) are both greater than the required 14 dB (0.95 probability of detection and 10^{-6} probability of false alarm.

FLIR

The following paragraphs briefly describe the major characteristics of existing FLIR sensors, and some of the features being considered for the second-generation FLIRs, primarily the use of image processing for enhancing the displayed image.

Current FLIR Systems

Current state-of-the-art thermal imaging systems generally fall into three categories: serial scan, serial-parallel scan, and parallel scan. All can be characterized by the generic block diagram of Figure 16.

Thermal imagery search effectiveness is limited by deficiencies resulting from

- Greater dynamic range in the scene than can usefully be displayed
- Constraints on system resolution

The display's dynamic range constraints have been partially resolved in the past by an a-c coupling of the detectors with a subsequent d-c restoration.

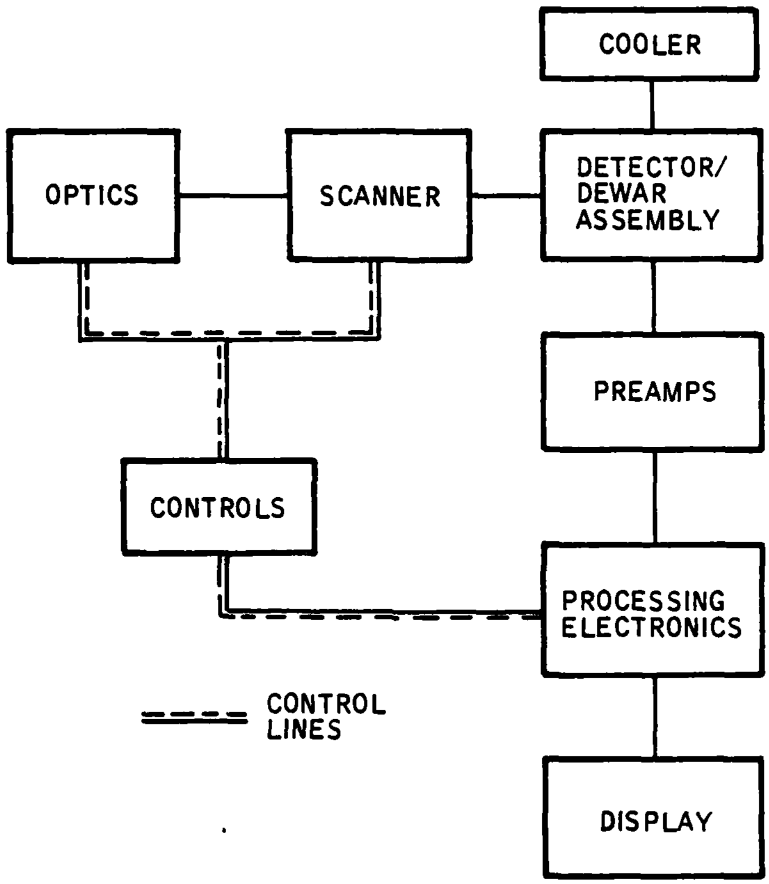


Figure 16. First Generation Thermal Imager Block Diagram

The serial-scan approach uses a two-axis scanning system to scan a detector or array of detectors such that each detector sees the entire field of view. This system has distinct advantages: detector responsivity equalization is not necessary, d-c restoration is easy, and fewer components are used. The result is a simpler system. The disadvantages are that high bandwidth detectors must be used, and the mechanical scanners tend to be complex, which is the inherent weak link in the system. High sensitivity in serial scan systems requires multi-element arrays in place of a single-detector element. The elements are used in the time-delay-and-add mode, which increases the effective signal-to-noise ratio by the square root of the number of detectors in the array.

Serial-parallel scan systems have similar characteristics to serial scan systems, except that more than one line is scanned at a time. The additional line scans are delayed for insertion into the output video at the proper time. This technique allows the horizontal mirror to operate at slower rates, but the delay and multiplexing electronics become more complex as the number of lines simultaneously scanned increases.

Fully parallel systems eliminate the need for delay lines. Current parallel scan systems are either viewed directly or electro-optically multiplexed to provide TV-compatible imagery to either an eyepiece, in the case of direct view systems, or to a vidicon TV camera. Parallel-scan systems have simpler scanning mechanisms and a greater sensitivity because of increased detector dwell time. Responsivity equalization and d-c restoration is complex in parallel systems because of the large number of detectors. Also, if a detector is lost, then one line of information is lost. This is common in large detector arrays.

System Design Considerations

Designing a FLIR for an optimum performance involves evaluating many components and subsystems. Most tradeoffs depend on the FLIR application, and different components are usually selected specifically for that application and for its environment. Examples of application-specific components are the field-of-view defining optics, the type of detector cooling, the FLIR stabilization scheme, the power supply, and the location and size of the display. There are several considerations, however, which can be studied in general because an optimum selection can be made that covers a wide range of applications. Two of the most significant of these considerations are the scanning method and the electronic processing technique.

Scanning Method

The most important decision in designing a FLIR is selecting the scanning method, because this affects choices of other components, as well as on the overall system performance. Two basic types of scanning are presently representative of most FLIRs: parallel scanning, and serial scanning.

Historically, the first high-performance FLIRs used parallel scanning. Since, in a parallel-scanned system each detector element dissects only a small portion of the FOV (one or two lines), relatively narrow bandwidths are required. A serial-scanned system requires that each detector dissect the entire FOV, resulting in a wide bandwidth. When FLIR development began, no detector material was available with the short-time constant needed for these wide bandwidths. Consequently, serial-scanned FLIRs were not developed. The application of short-time constant (Hg, Cd) Te detector arrays to thermal imaging systems made possible the required wide bandwidths for serial-scanned FLIRs.

Most present thermal imagers use a-c coupling. This results in an average value of zero for the video of each channel in a parallel-scanned FLIR, even though the average value of the thermal emission from the scene may vary from channel to channel. An imperfect reproduction of the scene results. An example of this effect is the difficulty of a parallel-scanned FLIR in detecting horizons. For many applications, horizon detection is a very desirable, and sometimes necessary feature for orientation during search and acquisition.

Recent techniques using CCD and CID arrays, together with the development of photovoltaic detectors exhibiting negligible 1/f noise, subtract background noise and dynamic channel balancing for parallel-scanned arrays, thus eliminating many of these problems.

In a parallel-scanned system which does not have the complexity of d-c restoration to a common thermal reference, hot targets tend to suppress the background on the channels which scan the hot targets. This occurs since the average value of the video in the a-c-coupled electronics is zero. From line-to-line, the average value of the scene radiance will vary. These values are considerably different when hot targets are present. Thus, background suppression results on those channels containing hot targets. In a serial-scanned FLIR, the average value of the video represents the average value of the entire scene. Thus, hot targets do not suppress the background on individual lines of the display. Another hot target effect is the undershoot resulting from inadequate low-frequency response of the video processing electronics.

The serial-scanned FLIR has a high scan rate with a correspondingly short dwell time. Therefore, for a fixed low-frequency response, a serial scanner exhibits less undershoot compared to a parallel-scanned system which has a much longer detector dwell time. However, the high scan rate in the serial-scanned FLIR results in a higher degree of mechanical complexity than parallel scanning.

A combination of parallel and serial scanning using time delay and integration can provide a higher performance at the expense of increased complexity on the focal plane if high-density area detector arrays become feasible. The ultimate in mechanical simplicity is the "staring" array which substitutes electronic for mechanical scanning entirely. However, we do not feel that staring arrays will be a candidate for a second-generation FLIR.

There are several constraining tradeoffs in designing a thermal imaging system. The visibility of image features is directly affected by the contrast between features on the display medium. Current thermal imagers offer some control over contrast through gain and brightness adjustments, either by automatically sensing the video data, or through the operator's control. However, these are global controls which cannot be optimized for the operator's target detection, recognition and identification tasks on all types of imagery. For example, clutter (the number of "target-like" objects within the field) is a significant factor in search effectiveness.

Problems in achieving adequate contrast sensitivity with current thermal imaging systems stem mainly from five factors:

- Large dynamic range of thermal imagery
- Low contrast levels of certain targets
- Limited dynamic range of the electronics
- Limited display dynamic range
- Operator workload (for manual gain/brightness control)

Diurnal and seasonal variations of thermal imagery can typically range over 30 degrees to 40 degrees for daily cycles, and up to 150 degrees for seasonal cycles. Such ranges of temperature indicate a need for gain/brightness control, but it need not be automatic to compensate for these slowly varying extremes.

FLIR imagery usually contains a portion of the horizon sky which typically falls 10 degrees to 40 degrees below the ambient ground temperature (and in some instances more than 100 degrees, e.g., a cool, clear night over a desert). Within ground imagery, terrain features may vary in temperature by 20 degrees - 30 degrees, while targets of military interest can exhibit contrast levels ranging from a degree or less (e.g., a camouflaged, passive target) to several thousand degrees (e.g., a jet exhaust). If, for example, the MRT (minimum resolvable temperature) at the IFOV (instantaneous field of view) is 0.1 degree, the dynamic range (peak image intensity to rms noise level) within the scene could be on the order of 10,000:1. Current SOA (state of the art) in CCD array processor dynamic range is typically an order of magnitude less (1000:1). Even more constraining, typical thermal imagery displays have dynamic ranges of 15:1 to 30:1, while the very best quality monitors available have less than 100:1 dynamic range.

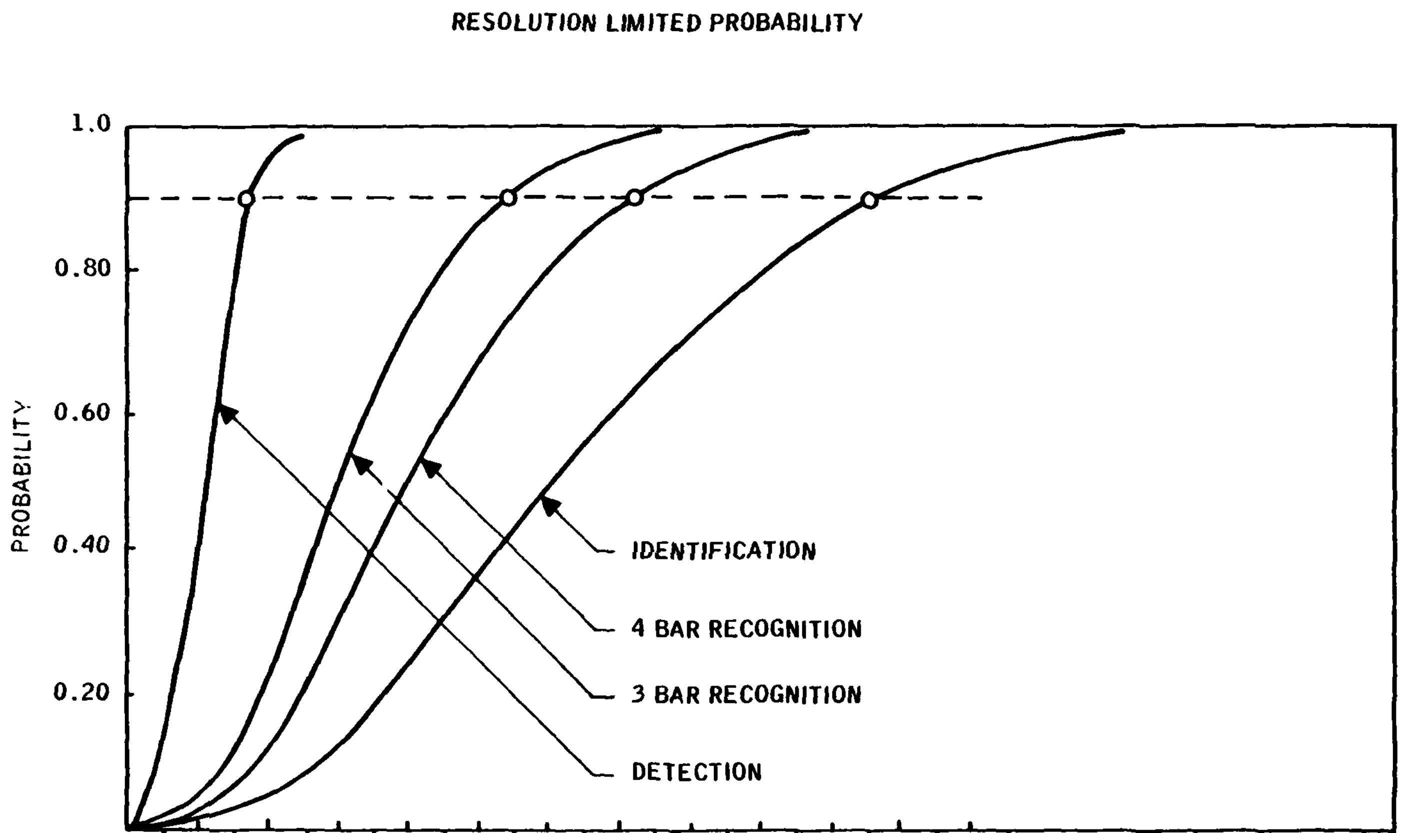
The design of any thermal imaging system involves a classical tradeoff between sensitivity, resolution and data rate. Given a specified, non-limiting aperture, this tradeoff is expressible by the proportionality

$$S \approx \frac{(F\#)^2}{\sqrt{R_d}}$$

where S is the sensitivity, F# is the system F number and R_d is the data rate. Since practical F#'s are constrained to $1 \leq F\# \leq 3$, and the desire for commonality of equipment dictates TV compatible data rates, this tradeoff is very limited in current systems. The result is designs that are inflexible with respect to changing environmental conditions.

State-of-the-art improvements in sensitivity and resolution are expected in future systems. However, there are theoretical and practical limitations to the degree of improvement that can be expected (e.g., the photon noise limits of thermal detectors, physical limitations on minumum detector size, number of detectors, etc.). Therefore, it is almost certain that the sensitivity/resolution/data rate tradeoff will continue to influence design in the future. (See Figure 17 for a graphic presentation of the tradeoff between resolution and target acquisition.)

The apparent temperature contrasts of typical targets, viewed against a terrestrial background, are very small. The corresponding analog voltage contrasts are also small, so that, if these



1	2	3	4	5	6	7	8	9	10	11	12	CYCLES/TARGET
4	16	36	64	100	144	196	256	324	400	484	576	PIXELS/TARGET RATIO 1:1
8	32	72	128	200	288	392	512	648	800	968	1152	PIXELS/TARGET RATIO 2:1
16	64	144	256	400	576	784	1024	1296	1600	1936	2304	PIXELS/TARGET RATIO 4:1

Figure 17. Probability of Target Acquisition as a *Function* of FLIR System Resolution

voltages are converted linearly into luminance contrast on a FLIR visual display, the operator would have difficulty recognizing and detecting (Figure 16). Atmospheric effects such as weather changes, humidity and haze also reduce contrast by reducing transmission of thermal information and reducing detection ranges (see Figure 18). Contrast commonly is increased by a-c coupling the detector signal, which removes the low-frequency background signal and improves the contrast on the displayed image.

Low-frequency information in the scene will be distorted or lost by a-c coupling. Image defects may result. In some cases, this behavior may mask other targets. Because the average value of the a-c coupling circuit is zero, the large positive signal response to a hot target will be followed by a smaller, but longer negative signal, which may extend all the way across the display.

Another constraining tradeoff in designing thermal imagers is the interdependence of sensitivity, resolution, and depth of field. This can be expressed in classical geometric optics terms as

$$\omega = \frac{S\ f'\delta}{2r^2}\ ,$$

where ω is the angular radius of the defocus blue circle, S is the lens speed, f' is the focal length, δ is the depth of field and r is the range. Thus, high resolution (ω) and sensitivity (high lens speed S) must result in a reduced depth of field (δ). The defocusing parameter Δ is measured in units of Rayleigh's ($\lambda/4$) tolerance on defocusing. These curves demonstrate that the MTF falls off very rapidly as a function of defocus at low F#'s.

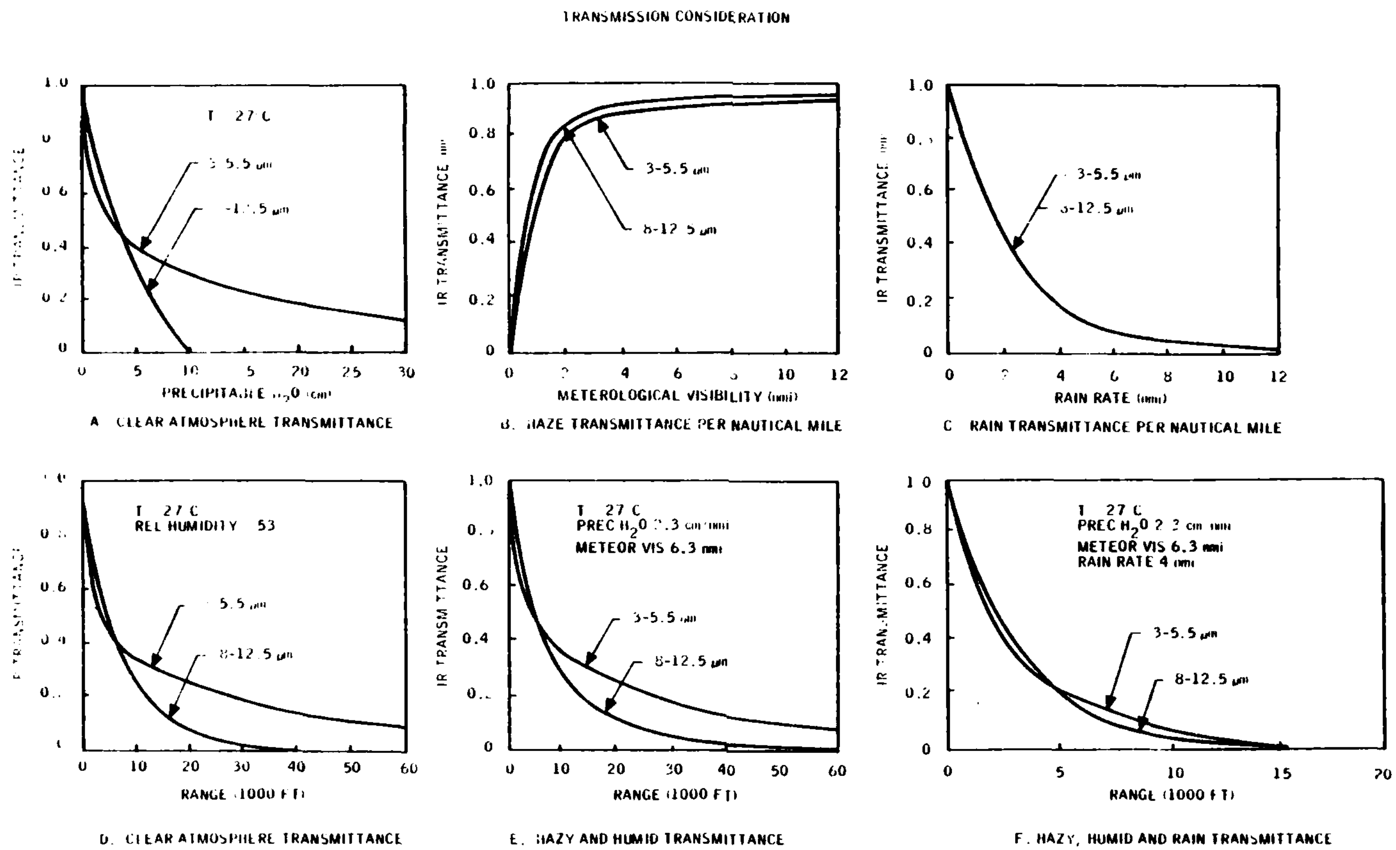


Figure 18. Transmission of FLIR Sensor Information as a Function of Range

Current systems use dual FOV (field of view) optics to overcome this problem to some extent. Targets are acquired with a wide FOV, low-resolution setting which has less of a depth of field problem, and then a narrow FOV, high-resolution setting can be selected by the operator for target recognition and identification. This limits search effectiveness at long range, however.

In addition to depth-of-field problems, there are other optical problems that affect system resolution. Thermal expansion or contraction of optical elements (particularly the germanium lenses used for thermal imaging) makes fixed focal length systems difficult to focus. Also, even if the system is focused on the optical axis, the optical PSF (point spread function) is not constant over the FOV.

Second-Generation FLIR Configurations

Advances in detector and CCD/CID technologies portend large, one-dimensional or two-dimensional arrays capable of multiplexing and time-delay integration at TV rates. Scan configurations that are under consideration because of these developments include series-parallel configurations, the parallel scan-pushbroom array, staring arrays, and a dithered array concept. (Note the latter is simply a hybrid of a scanned and a staring array.)

The parallel scan, pushbroom-type system consists of one or more multi-element arrays positioned horizontally across the field of view. The vertical scan is mechanical, and the horizontal scan is implemented by CCD multiplexing. Each array will consist of as many detector elements as the required horizontal resolution. D-c coupling and background subtraction will eliminate the need for d-c restoration. Responsivity equalization will be attained through an AGC amplifier controlled by a ROM, or from calibration signals derived in real time. Since the detectors are scanned vertically and sampled once each horizontal line, less bandwidth is required, higher sensitivity is attainable, and imagery correlations in all directions are maintained. Because background subtraction and responsivity equalization will be accomplished on-chip, good picture uniformity and horizon definition should result. This type of scan method is also directly TV-compatible.

Now being explored are second-generation FLIR designs incorporating improved d-c restore techniques, adaptive contrast enhancement, and automatic gain and brightness controls (Figure 19) which would overcome the current dynamic range limitations.

Adaptive or selectable intra- and inter-frame averaging will reduce the effect of the sensitivity/resolution design constraint. Similarly, adding resolution restoration techniques (e.g., super-resolution) may reduce optical aperture size requirements at longer wave-lengths, or augment an automatic focus control function to provide uniform resolution over the entire frame.

Incorporating these image-processing functions into a second-generation FLIR design effectively requires careful attention to the interaction between the various functional components of the FLIR, such as the interaction between the detector array/scan format configuration and implementation of the various image processing functions. For example, initial studies of super resolution algorithms for overcoming the Rayleigh limit quickly identified the need for oversampling the image to avoid aliasing effects.

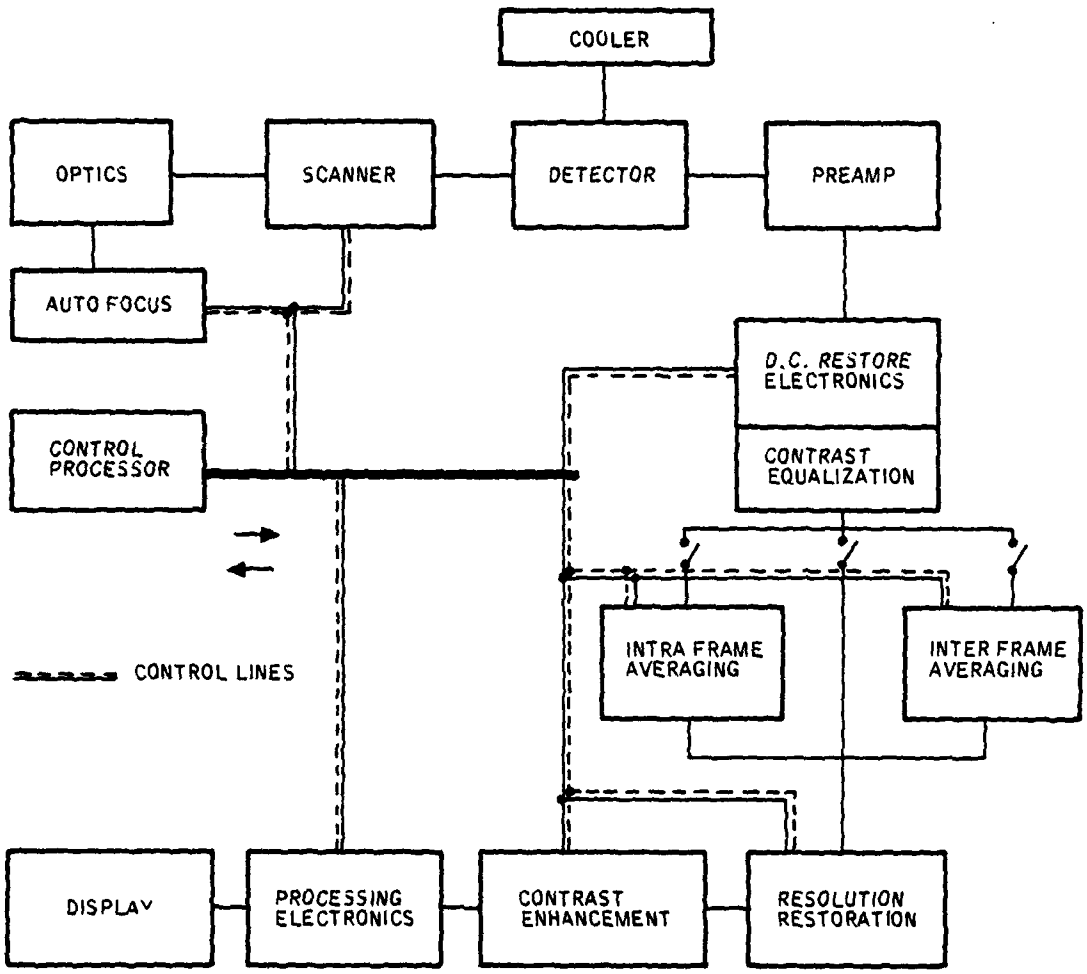


Figure 19. Second Generation Thermal Imager Block Diagram

Video-image processing tradeoffs and selection are related to the scanning techniques chosen. A parallel scanned system requires parallel processing. Thus, the number of electronic channels required is equal to the number of detector elements in the array. Two basic choices are possible to convert the video signals to an optical image. One is by electronic multiplexing using CCDs or CIDs followed by conventional TV display. The other approach uses parallel processing to an LED array which is scanned in synchronism with the detector array to produce the display. For this approach, the controls, such as gain, level, and image inversion must be applied to each channel, and the channels must track each other to maintain image quality. If this method is used, the display is an integral part of the FLIR and only direct viewing is possible. For remote viewing, TV camera and monitor are required and add further complexity to the system.

A basic FLIR sensor consists of optics, a scanner, detector and cooler, electronics, and display. In designing a FLIR, it is necessary to account also for the characteristics of target and background, intervening atmosphere, and the human operator. Incorporating image-enhancement techniques into FLIRs will, of course, have the most significant effect on the system's electronics. Conversely, processing on the focal plane will be the most significant constraint on image enhancement.

Focal plane processing will be determined by CCD and CCD-compatible technologies. Background subtraction and a detector array readout using CCD multiplexing are already near reality. CCD or CID delay lines will provide the memory to implement many of the enhancement algorithms.

This brief discussion of potential second-generation FLIR configurations has been merely to focus on anticipated future systems. As such, the discussion is not intended to be complete but merely to reflect current thinking.

FLIR SUMMARY

For navigation and effective target surveillance the FLIR scanner must cover 40 to 60 degrees across the horizon and 20 to 30 degrees in elevation. This coverage is approximately equal to the radar footprint. For detecting small ground targets such as trucks, tanks and missile launchers, approximately 1000 pixels are required in the horizontal axis. After detection, the system may zoom or change optics to provide a 1-1/2 to 3-degree field of view for target recognition. The system operates in the 8 to 12.5 micron region with 60 fields per second.

RADAR SUMMARY

A number of points about radar are of note:

* Angular resolution (antenna size) is the driving function, which forces the radar designer toward MMW frequencies to keep the size of antenna apertures reasonable.

* Terrain-following (X and Ku band) radars use relatively large antennas. Some airborne MTI surveillance systems (SOTAS) require a 16 foot antenna for a 0.7 degree beamwidth. Therefore,

microwave frequencies (Ku band and below) are not practically suited for the space available in a small, high-performance aircraft.

* Synthetic Aperture Radars (SAR) are not suited for real-time displays due to processing requirements.

* MMW radars operating at 35 GHz or 94 GHz can provide a high resolution data output. The limiting factor on maximum detectable range is rainfall attenuation. However, ranges on the order of 3 - 7 km can be expected with a probability greater than 0.99, using the western Europe weather model.

* Passive radiometers operating at MMW frequencies typically have a maximum range of less than 1000 feet for conventional targets.

FLIR AND RADAR SUMMARY

Both systems have several points of comparison:

* Both systems have reasonable detection ranges in good and poor weather.

* Both systems cover an adequate footprint.

* The systems are not directly compatible due to resolution differences (Radar $\simeq$ 1 degree beam and IR $\simeq$ 0.8 MR pixel)

* The size of the system is such that it will fit in small attack and V/STOL aircraft.

Table 4 presents estimated target detection distances for a 2.7 x 5.2 meters target using a 3-watt, 35-GHz radar and a 1000-pixel, 40-degree FOV FLIR system. As expected, the radar has almost twice the range of the FLIR system under clear atmospheric conditions. However, 4 mm/hr. of rain attenuates the 35-GHz radar by 38 percent and the FLIR by only 25 percent. The 16-GHz radar is not significantly attenuated by the rainfall.

TABLE 4. ESTIMATED RADAR AND IR DETECTION DISTANCES

	Radar		FLIR	
	35 GHz	16 GHz	1°C T to B*	5°C T to B*
Clear Atm.	4.5 KM	5 KM	2.4 KM	2.8 KM
Rain 4 mm/hr.	2.8 KM	5 KM	1.8 KM	2.1 KM

* T to B = Target to Background

SECTION 4
SELECTED MULTISENSOR DISPLAY DESIGN CONCEPTS

Several approaches were considered for combining displays and how they relate to mission activities. From this analysis, two new concepts were developed. They represent a new method of preprocessing and combing the two sensor outputs on a single, unified display. The two methods are similar, but one is achromatic and the other uses color.

BACKGROUND

Many of the direct optical and electrical *combining* approaches are listed in Figure 20. However, the combined display must offer benefits when applied to the aircraft and its various missions. The battlefield-interdiction and close-air-support mission are typical applications of current Navy carrier aircraft and forthcoming VSTOL aircraft.

Discussions with pilots and an analysis of time lines indicate high workloads and a high probability of errors during the penetration and attack periods, with either good or limited visibility. The low-altitude, penetration period requires information for navigating and for avoiding terrain. The attack period requires data for target detection, recognition, and action (e.g., a decision about which weapon to use).

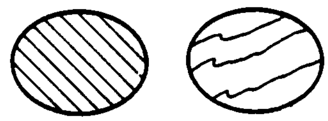
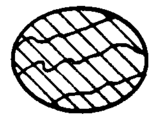
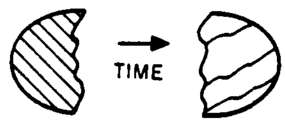
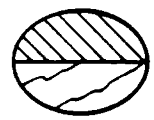
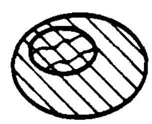
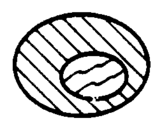
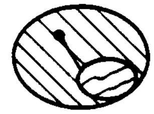
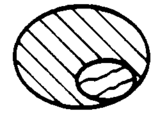
1.	IMAGES FILLING THE WHOLE SCREEN MY BE SHOWN SIMULTANEOUSLY ON MULTIPLE SCREENS.	
2.	IMAGES FILLING THE WHOLE SCREEN MAY BE SHOWN SIMULTANEOUSLY, SUPERIMPOSED UPON EACH OTHER ON A SINGLE SCREEN	
3.	IMAGES FILLING THE WHOLE SCREEN MAY BE SHOWN SEPARATELY, JUXTAPOSED IN TIME, ON A SINGLE SCREEN.	
4.	IMAGES OCCUPYING EQUAL PROPORTIONS OF THE DISPLAY SPACE MAY BE SHOWN SIMULTANEOUSLY ON A SINGLE SCREEN. THIS IS KNOWN AS A SPLIT-SCREEN PRESENTATION.	
5	A FULL-SCREEN IMAGE MAY BE SHOWN WITH A DESIGNATED PORTION OF IT OVERLAYED BY THE SUPERIMPOSED INSET OF A SECOND IMAGE.	
6.	A FULL-SCREEN IMAGE MAY BE SHOWN WITH AN INSET OF A SECOND IMAGE REPLACING A DESIGNATED PORTION OF IT.	
7.	A VARIANT ON NUMBER 6, WITH THE INSET IMAGE PLACED IN ONE CORNER OF THE MAIN IMAGE, AND A MARKER INDICATING AN AREA OF SPECIAL INTEREST IN THE LATTER.	
8.	A VARIANT ON NUMBER 7, WITH AN INSET AGAIN PLACED IN A CORNER OF THE MAIN IMAGE IN THIS CASE, THERE IS NO MARKER, AS THERE IS NO SPECIAL RELATIONSHIP BETWEEN THE TWO IMAGES.	

Figure 20. Methods of Presenting Multiple Images

With high visibility, the penetration period requires only the conventional instruments and, possibly, a map display. However, with limited visibility, the pilot needs a visual presentation of the real world. This is best achieved by an imaging sensor such as LLLTV or FLIR. The loss in resolution, field of view, color and other ground cues makes distance and range judgments more difficult for terrain-avoidance maneuvers. An imaging display with range data should reduce errors in judging ranges.

Detecting ground targets under both limited and unlimited visibility conditions are enhanced when sensors in different regions of the spectrum search for target signatures. FLIR and LLLTV detect heat in the infrared regions (near and far). Radar detects reflections and the scattering of high-frequency radio beams.

Because of the frequency separation of the sensors (Figure 21), it is unlikely that a target could escape being detected by both IR and radar, unless advanced camouflage techniques are employed.

The probability is also very high that the military target being sought on the mission will be sensed by both sensors and that false targets (such as large animals for IR and rock reflections for radar) will be sensed by only one of the two sensors.

On many current missions, two target passes are required, the first to detect and verify the target and the second to launch the weapons. The addition of FLIR and radar signature data on the same imaging display used for navigation may allow a single pass for detecting, verifying launching the weapon.

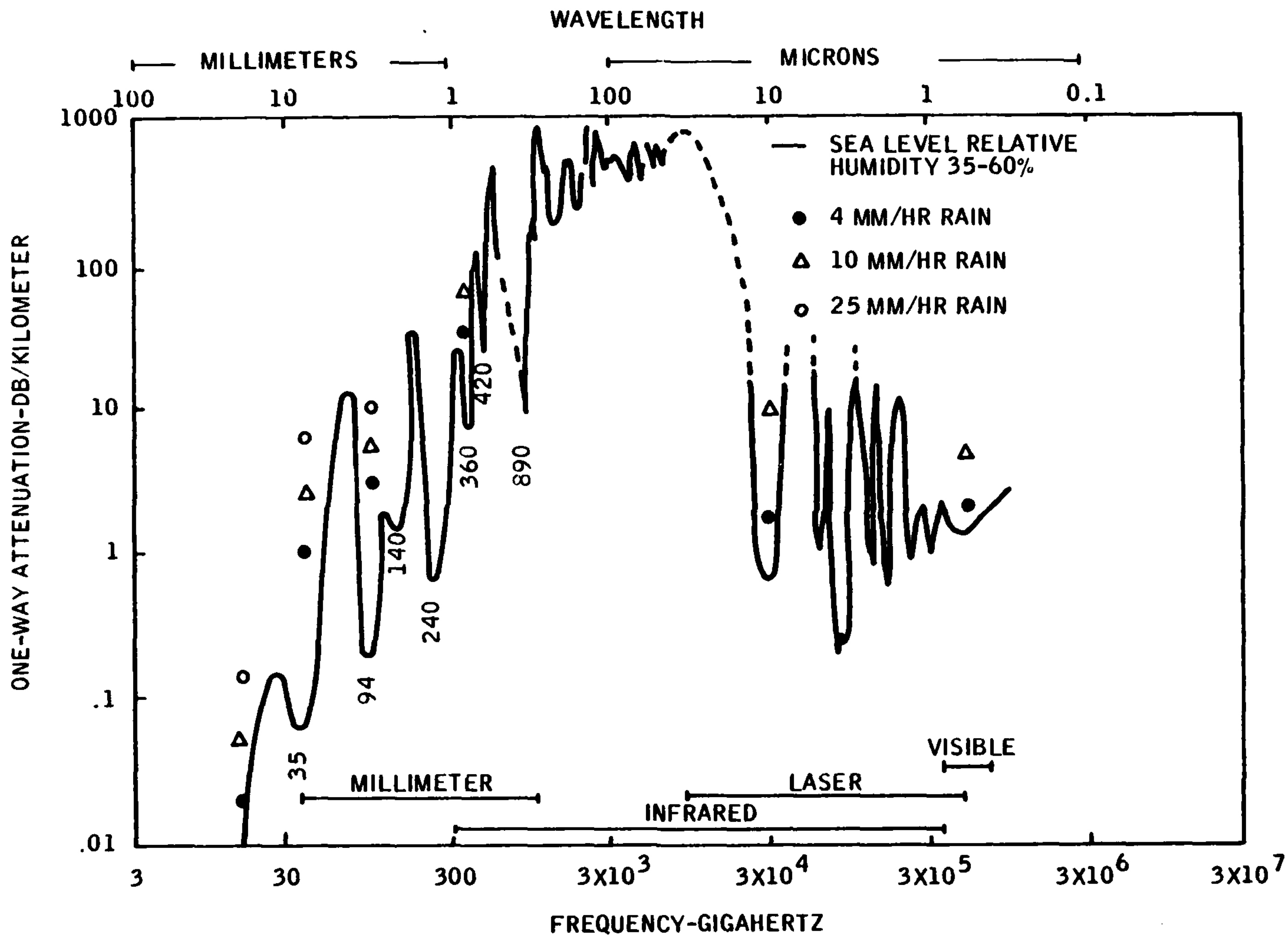


Figure 21. Atmospheric Attenuation versus Frequency[1]

[1]Victor W. Richard, MMW Radar Applications to Weapon Systems, BRL Report, Memo Report 2631 Page 11, 1976.

COMBINING SENSOR INPUTS

The problem is to define how the two data sets could be meaningfully and clearly combined in one simultaneously presented picture. Traditionally, each sensor display has been presented separately to the operator (multiple-display format). Some consideration has been given to presenting both on one display, thus saving panel space in the cockpit. Using this multifunction display concept, the operator would switch back and forth, as desired, between FLIR and radar.

Since the focus of this study was to go beyond such formats, the question became one of determining how to present both sets of sensor data simultaneously on one surface.

Superimposing the two sensor images did not appear to be a feasible alternative, primarily because of the differences in signature information, resolution, and display format. The resulting combined picture would almost certainly confuse or distract the operator rather than help.

A more attractive alternative was to use the information from one sensor to annotate the image presented by the second. One of the weaknesses of FLIR is the lack of good range information. As discussed above, one weakness of the radar image is its poor resolution. Since the FLIR image provides a good representation of the terrain, it appeared to be the most logical candidate for the primary display. Radar data could then be used to supplement FLIR data by adding both target detection and ranging information.

Image-processing and automatic-target-detection algorithms are being actively studied by a number of investigators. Currently available hardware and software provided the capability for automatically scanning sensor output, detecting targets of interest, and displaying the cue on the operator's display. In the combined display concept, sensor returns from both FLIR and radar would be preprocessed. The displayed FLIR image would be thus annotated with both FLIR and radar target cues. Using different cues for each sensor, the operator would quickly determine which sensor had picked up a given target. A third cue would indicate that both FLIR and radar had detected the same target.

Adding radar range information to the FLIR image would further enhance its utility. The method of providing this information (i.e., how to display it) is another issue. Two methods are discussed more completely below.

SENSOR IMAGE PROCESSING

Typically, hot objects and good emitters appear on IR displays as brighter and with higher contrast. Highly reflective objects also appear on the radar display as brighter and higher contrast objects. Therefore, the increase in signal strength above a threshold may indicate a possible target.

After 1985, it is assumed that the sensor imagery will be preprocessed by automatic target screening algorithms controlled by on-board computers. Each sensor output will be automatically screened prior to its presentation on the operator's display. Potential targets detected by such a system will be highlighted on the display in some manner. Currently available systems detect targets at a fairly high level of probability. Post-1985 systems will perform with even greater accuracy. Each sensor output will have its own preprocessor and its own associated processing algorithms. Thus, no matter what the final display mode, it will be possible to separately define radar-cued targets, IR-cued targets and joint IR-radar cued targets. The question is how best to display this cue to the operator. Two important considerations about cue selection include:

1) The cue must be easily seen and recognized by the sensor operator.

2) The cue itself should not obscure either part or all of the target, nor should it obscure parts of the immediate background. The background itself may contain important clues useful to the operator when identifying a target.

The best method of achieving the above two goals appears to be through highlighting. The target and its immediate surroundings could be cued by changing the luminance and/or the dynamic range of the locally cued area relative to the rest of the displayed scene. In a color display, the cued area could be colored distinctively, making it highly visible to the operator. Further information about the target could be provided by changing the shape of the highlighted area.

DISPLAYING MULTIPLE SENSOR DATA

Given that the operator has two or more sensors onboard, the data can be displayed in a variety of ways. The traditional approach is to present individual sensor data on separate displays (multi-display approach). Another possibility is to use the same display surface to successively present one or the other sensor's data (multifunction approach).

Each of these display alternatives presents problems for the operator. In either the multidisplay or multifunction method, he may miss important information on one display while looking at the other. Additional problems include the necessity of constantly changing orientation from one form of data to another very different one. That is, range, resolution, and content are quite different on the two displays. It may also be difficult to locate identical points on the two displays when, for example, the radar display indicates a potential target which the operator would like to examine on the FLIR display.

The general combined-display concept selected for testing attempts to remedy these problems by presenting both sensor returns simultaneously on a single display. While the other two concepts can be functionally considered as combined display concepts, they do present the above problems. Thus, while the multi-display might, in fact, be a single split screen display, it does not truly combine the two sensor outputs in the best possible way from the operator's point of view.

The most useful combined display would take the information from both sensors and combine it prior to display. The alternative method derived in this study uses the FLIR image as the basic operator display. The FLIR image is highlighted and modified in the following ways. Range data from the radar is added to the FLIR display such that the operator can determine relative distances of objects on the FLIR image. Using automatic target screening devices, both the FLIR and radar images are preprocessed. Targets detected by either FLIR or radar are highlighted on the display. The display of these target cues is shape-coded such that the operator can determine which sensor cue is being displayed. If both sensors have picked up the same target, the area would be highlighted using a third shape cue.

Such a display should provide the operator with all the information required on a single display surface in a format that is very easy to use. It is assumed that the operator's scanning time would be reduced, and target acquisition enhanced.

The above display could further be presented in either color or black and white. Figure 22 illustrates this combined display concept in an achromatic display. Targets are highlighted by changing the dynamic range of the immediate target area. The different shapes represent different sensor returns, as discussed above. The dashed line through the center of the image is radar range information.

In Figure 23, the same image presented in Figure 22 is shown, but with the addition of color. In this image, color is used in two ways. The cued targets are highlighted using color contrast to make them more visible. The different sensor returns are cued by shape in the same manner as in Figure 22.

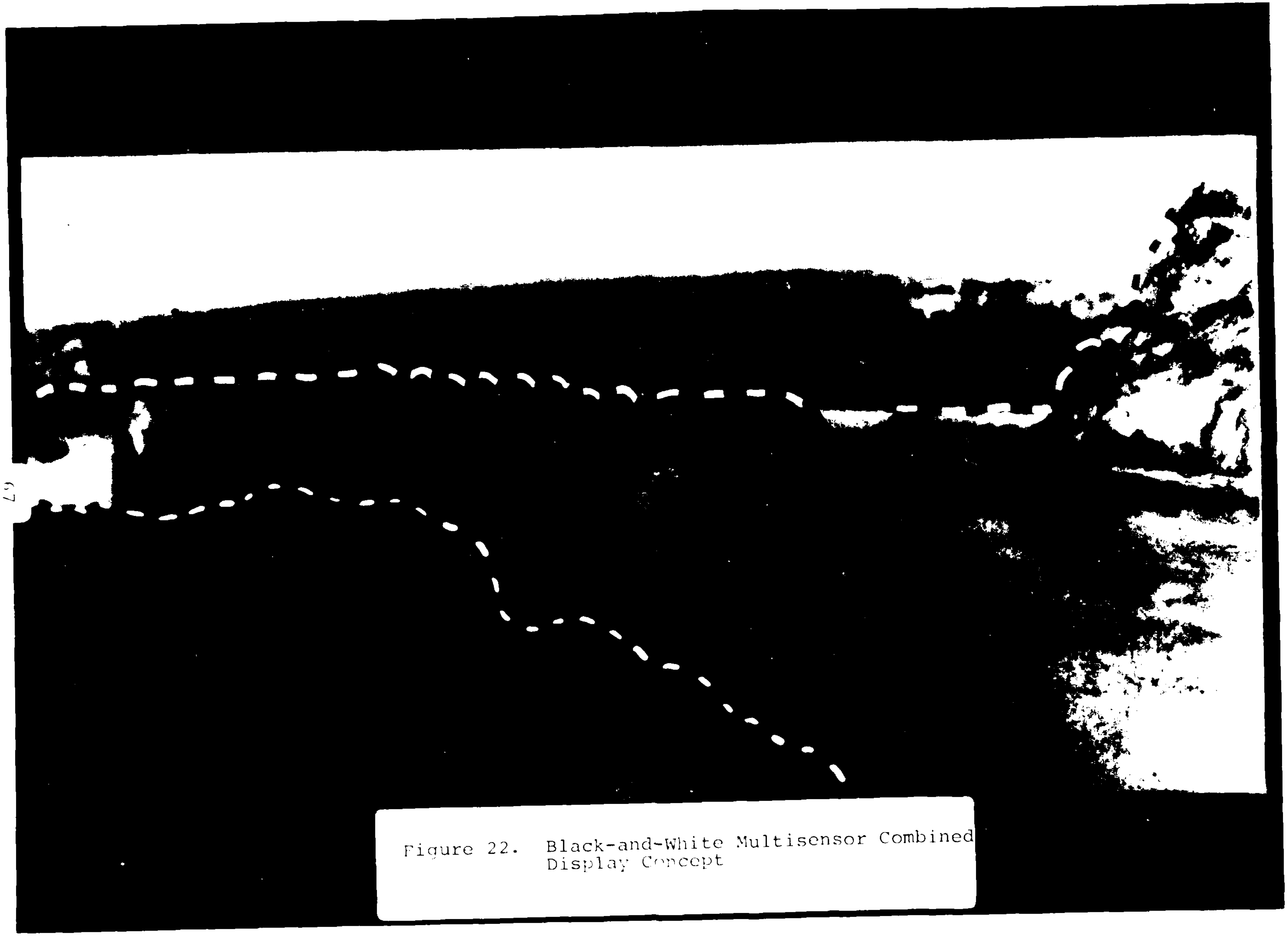


Figure 22. Black-and-White Multisensor Combined Display Concept

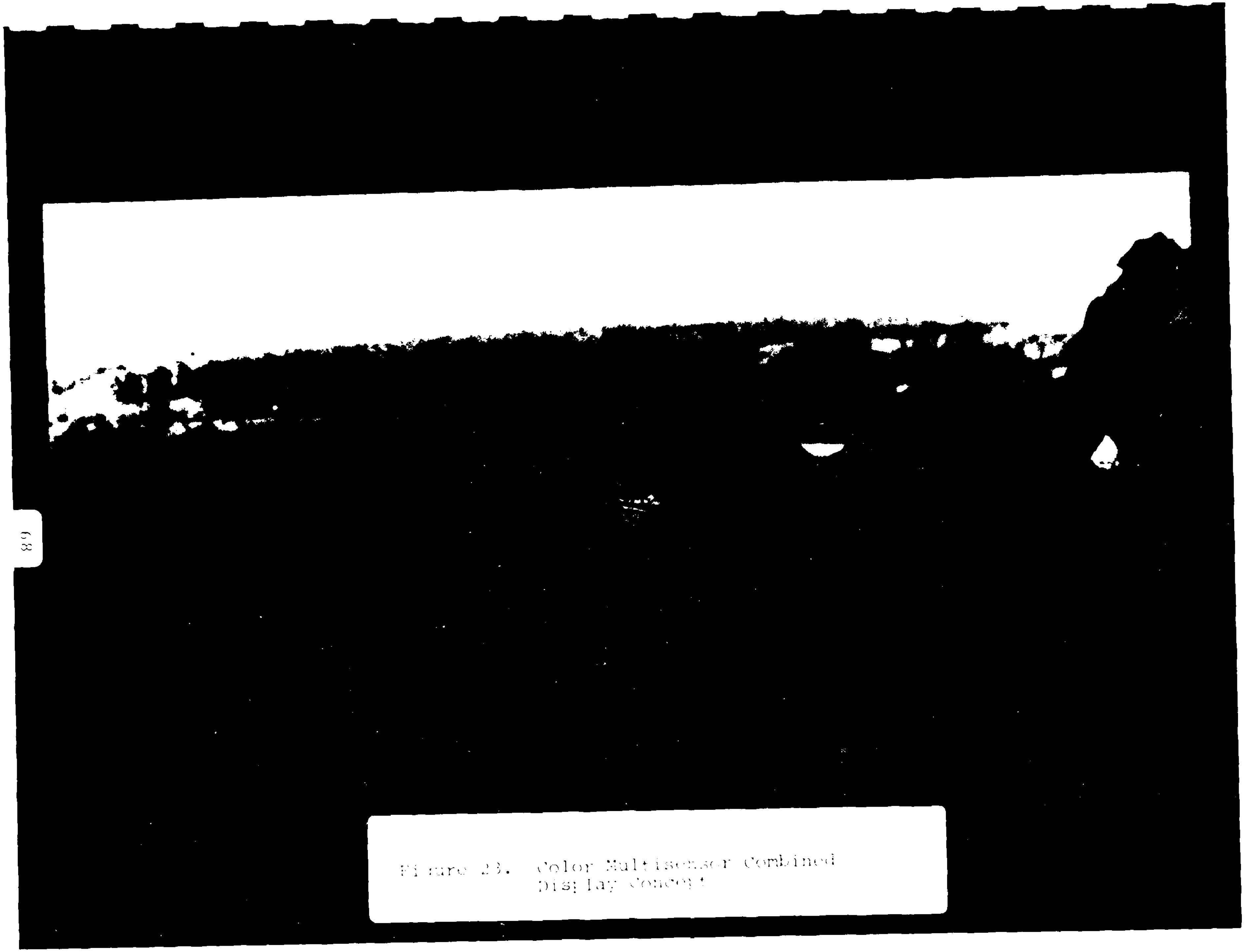


Figure 23. Color Multisensor Combined Display Concept

Color is also used in this image to provide radar ranging information. Objects at close range are colored red, those at intermediate range, green, and those at a far range, blue. Thus it should be possible for the operator to see color-cued targets and to estimate their approximate range. Color range data would also provide a navigational cue to the operator.

While the features of the combined displays illustrated in Figures 22 and 23, appear to provide obvious advantages to the operator, particularly in a single-seat attack aircraft, they have not been tested experimentally. During the current contract, a test plan for evaluating multisensor, combined displays has been developed. The test plan is presented in Section V. The actual test will be conducted in Phase III.

SECTION 5
EXPERIMENTAL DESIGN

Four multiple sensor display concepts were tested using dynamic imagery with various targets embedded and highlighted cued in selected ways. Two of these display concepts combined display formats while the other two represented uncombined display formats. For the combined display formats, the FLIR image display was the basic operator display presentation. Radar data was then combined into this display, supplementing the FLIR data by adding both target detection and ranging information. The two combined display formats differed in that one was achromatic while the other used color.

The two uncombined display formats presented FLIR and Radar information separately in conventional displays. Both uncombined display formats were achromatic. These display formats differed in that one used two separate but simultaneous displays which employed two monitors (multidisplays), while the other used a single display monitor (multifunction). With this display concept, the operator was required to switch back and forth, as desired, between FLIR and radar displays.

In each experimental condition, the imagery displayed on the monitor(s) simulated the penetration phase of a mission the low and fast approach to a battlefield. The aircraft's altitude was approximately 200 feet with an airspeed of 200 knots. The low-altitude flight represented an aircraft flying into enemy territory under the radar net to avoid being detected. The imagery, as viewed by the observer, contained military, and false targets.

The aircraft with automatic target screening device, automatically detected targets with both its FLIR and radar sensors. A total of 30 targets were embedded in the imagery, the sequence of which lasted approximately five minutes.

The 30 targets were randomly embedded throughout the five-minute imagery display. Twenty-four of these targets were highlighted, while six were not. The targets and their surrounding terrain were highlighted by increasing each image's contrast through an expanded dynamic range. Highlightings were shape-coded to signify the specific sensor detection device. Circular highlightings represented detection by both FLIR and radar sensors. Square highlightings represented detection by the FLIR sensor only and triangular highlightings represented detection by the radar sensor only. Table 5 summarizes the target characteristics for this imagery display.

TABLE 5. HIGHLIGHTING SHAPE BY SENSOR

Target Type	Circle Both Radar and IR	Square IR Only	Triangle Radar Only	Unhighlighted Undetected
Tank (Military)	2	2	2	2
Helicopter	2	2	2	2
Burner (Non-Military)	2	2	2	2
False Target	2	2	2	-

All four display concepts, in addition to the aforementioned target detection information, afforded the operator radar ranging information as well. In the color, combined-display condition, this information was conveyed through the color bands spanning the display screen. The close range was colored red, the intermediate range green, and the far range blue. In the black-and-white combined display condition, radar ranging information was conveyed by boundary lines superimposed on the FLIR display. Uncombined display conditions revealed radar ranging information on the sectioned PPI terrain avoidance radar, displayed on a separate monitor. In the single-monitor display, a switch was used to select either the radar displays or the FLIR display, while in the two-monitor display, the radar-range display was presented concurrently with, but separate from the FLIR-image display.

The partial PPI radar also displayed signatures. Helicopter signatures appeared as horizontal oblongs (▬), tanks as circles (●), and burners as vertical oblongs (▮). Highlighted targets were all presented with a circular ring surrounding the target ((⊖)). The absence of a ring represented an unhighlighted target. Consequently, the uncombined display detected targets from both the radar and FLIR displays. While the combined display conditions only afforded the subject a single source of target detection information, this display combined the information from both sensing devices onto the single-screen display. The differential information, then, was affected by the number and kind of highlighted targets presented.

In summary, then, each subject performed three tasks: 1) "point-of-impact," 2) target detection, and 3) tracking.

All four display conditions annotated the imagery display with a cross hair, which showed "point-of-impact" information to the subject. The uncombined condition displays showed the impact point on the partial PPI terrain-avoidance radar display. The subject responded to this information by indicating the range zone at which this projected point of impact was occurring. If the cross hair was in the near range zone, the observer's task was to pull back a three-position lever with his left hand; for the far-range zone positioning, the lever was pushed forward. An intermediate range zone was indicated by placing the level in a center position. Lever adjustments were not uniformly distributed throughout the five-minute session, consequently lever adjustments were necessary anywhere from every 1 to 13 seconds. The changes were dictated by the terrain. The range zones changed 50 times during each experimental run.

The above described "point-of-impact" task was the subject's primary task in each experiment. Two other concurrent tasks were required of each subject for every experimental condition. The secondary task of this experiment was that of "target detection." For this, subjects were required to pronounce the name of each target type (helicopter, tank, burner or false target) as soon as each was recognized and detected.

The third and least significant task in this experiment was one of tracking throughout the five-minute run. A right-handed, spring-loaded joystick was employed to control a randomly moving dot about a prescribed area. The subjects' task was to attempt to keep the dot inside a circle embedded within this area. The tracking task appeared superimposed on the combined and FLIR display for each subject across all conditions.

Thirty-two right-handed male subjects were used. The subject's ages ranged from 19 to 43, with the made being in the mid-20s. Each subject participated in two experimental conditions: one combined and one uncombined. Half of the subjects viewed the color combined display, while the other half viewed the black-and-white combined display for their combined condition experimental trial. Similarly, half of the subjects viewed a single-monitor display, while the other half viewed a double-monitor display for their uncombined condition experimental trial. Half of the subjects first participated in a combined condition and then an uncombined condition, while the other half received the opposite treatment: first uncombined and then combined. Consequently, four subjects were randomly assigned to each of the eight cells possible. The following listing displays the design:

8 Subjects	8 Subjects	8 Subjects	8 Subjects	
Color	Color	Black & White	Black & White	Combined
One math-function monitor	2 Monitors one-FLIR one-Radar	One multi-function monitor	2 Monitors one-FLIR one-IR	Uncombined

All subjects were first exposed to a training session (varying with condition: see training procedures section) then an experimental condition. Following a short break, subjects were then exposed to a second training session, followed by a second experimental condition.

An entire session (i.e., two experimental conditions plus two training sessions) for each subject lasted approximately two hours. Subjects were paid $15 for their participation.

SECTION 6
EXPERIMENTAL STIMULUS GENERATION PROCEDURE

A five-minute film simulating the cockpit view from a low and fast approaching aircraft into a battlefield was needed as the major stimulus material for this study. Due to the nature of the target detection and point-of-impact data needed to make this film, a complex series of procedures were developed to produce a finished product.

To simulate the pilot's perspective from the cockpit of a low-flying, high-speed aircraft, the initial task was to film a dynamic aerial view over an expanse of land. This was to serve as the background terrain for the needed imagery display. A Hiller UH-12E helicopter was equiped with two cameras: a Telemation 1100 camera (with a red-extended vidicon) and a high-resolution 16 mm Arrow Flex Model S. Both were secured to shock mounts to reduce vibrations. A portable tape recorder on the helicopter transformed the video imagery onto video tapes. Although two types of imagery film were collected (red extended vidicon and high-resolution 16 mm films) the imagery filed exclusively by the Telemation 1100 camera with red-extended vidicon was used for our experimental imagery. This decision was made by Commander Donald Hanson as he judged it to be a closer approximation of IR imagery simulation. The helicopter, flying at approximately 60 knots, covered areas of Minnesota's north shore, flying low in a generally northeasterly direction from the shoreline through the valleys and surrounding rolling hills. The steep, tree-covered hills presented an excellent navigation problem and the clearings in the valley offered many potential target sites.

The video tapes from the helicopter flight were then refined in several ways. The film first needed to be edited to more closely approximate the high-speed (200 knots) of the low-flying aircraft intended for simulation. The film also needed to be prepared so that frame-by-frame target detection and point-of-impact data annotations could be subsequently performed. This was done by transforming the video tapes onto video discs using an Arvin Echo video disc recorder/player.

Initially, every tenth frame of the original video tape was recorded onto the video disc. That is, three frames per second of the original film (at 30 frames per second) were now recorded. After processing each frame a new tape was developed which contained a series of 3 identical frames ($\frac{10}{3}$ (60)$\approx$200). This process transformed the video tape to reflect the air speed of a high-speed (200 knots) military aircraft.

The next step in this procedure called for frame-by-frame annotations of point-of-impact and target detection data. Point-of-impact information was needed for every single frame in the entire film segment, target detection data annotations to the film were needed only for a total of 600 frames. The entire film segment contained 30 embedded targets, and each target appeared for two seconds of real time. Therefore, 20 different frames per target were used for annotation. Targets were embedded randomly throughout the film segment. Their spot appearances in the film segment were dictated exclusively by the nature of the filmed terrain. Targets were generally embedded in clearings. Such areas facilitated developing a realistic film segment in that targets could be embedded in appropriate places from frame to frame, thus appearing stationary. Their movement across the screen only reflected the aircraft's movement as it approached, and eventually flew over them. Such movement, then, reflected only changes in distance.

Once the entire imagery tape was properly edited and recorded onto the video discs, a frame-by-frame procedure for incorporating the range detection data was instituted by using a Stanford Technology Corporation Model 70-E image computer. The video signal of each frame was digitized and stored in the memory of the Model 70-E. With a trackball and cursor, two boundary lines (which divided the imagery display into three regions) were then drawn on the video monitor projecting the imagery frames. These boundary lines were stored in the graphics memory of the computer. The execution of the computer program overlayed the line with the digitized imagery.

While the shapes and angles of the boundary lines were determined by the shape and angle of the horizon as projected in each imagery frame, the distance between the boundary lines was dictated by the nature of the terrain projected in each imagery frame. Very flat terrain dictated widely spaced boundary lines with little terrain below the lower boundary line, mountainous terrain was reflected by greater distances between the bottom of the screen and the lower boundary line and, consequently, smaller distances between the upper and lower boundary lines.

The overlayed boundary lines on the digitized imagery frame were employed differently in two distinctly different functions as executed by the computer program. In one condition, white dashed lines were actually superimposed onto a black-and-white imagery frame resulting in an imagery display sectioned into three parts (see Figure 22).

The second function used the boundary lines drawn with the track-ball and cursor as delimiters for the three sections, which were then filled in with colors. That is, the region between the bottom of the screen and the lower boundary line was colored red, the region between the two boundary lines green, and the region between the upper boundary line and the horizon blue. Consequently, in this, the nonachromatic representation of each imagery frame, near distances to the aircraft were colored red, middle distances green, and far distances blue (see Figure 23).

A third function of the Model 70-E program projected each digitized imagery frame without the overlayed boundaries. Consequently, this entire procedure resulted in three distinctly different end products for each imagery frame, each to be employed as stimulus material for different experimental conditions. (See Experimental Design Section for details.) One presented the imagery frame in black and white with no boundary lines overlaid. This was the uncombined FLIR conditions. Another presented the imagrey frame in black and white with two white dashed lines superimposed upon it. This was the black and white combined display, the third presented a color-coded imagery display, with each of the three regions reflected by a different and distinct color. This was the color-combined display.

A cross hair, centrally located on each imagery frame, was also embedded. This cross hair, combined with the boundary lines overlay, offered the subject all the needed information for the "point-of-impact" task. (See Experimental Design Section for details.)

As mentioned earlier, some imagery framed needed target detection information, as well as point-of-impact information. For these imagery frames, additional procedures similar to the ones just outlined were necessary. Initially, black-and-white slides of all pertinent targets (helicopter, tank, burner) had to be developed. These slides had to reflect each target as detected from varying distances. Consequently, multiple slides of each target, each slide reflecting a different sized target, were processed using a Pentax KX camera. A series of 20 photographs were taken at successive distances from the target.

With a Telemation 100 camera and a mast 127S Random Access Projector, each slide was digitized and stored in memory. The location of the to-be-embedded target was then set by the cursor indicator and the threshold for the video image was set by the trackball. After this needed information was entered into the Model 70-E, the program was able to embed the target in the background imagery in each selected video frame. The program also allowed for one of four highlighting options, based upon sensor detector: 1) circle (both), 2) triangle (radar), 3) square (FLIR), 4) no highlighting (no sensor). Highlighting options were determined randomly as each target appeared twice in each highlighting condition option (see Experimental Design section for detail.)

The highlighted area of interest underwent a computer operation to enhance the target. The area was expanded linearity to the maximum limits of the dynamic range. The whites become whiter and the blacks blacker. On the color concept, the area was coded in yellow. A triangle represented the detection of the radar, a square by the IR, and a circle by both. The single combined displays contained the three highlights. The uncombined FLIR display contained only highlights sensed by the IR system. The radar contained highlights sensed by the radar system. After specifying a location for a given target, 20 successive frames underwent this procedure. The efforts of this procedure resulted in the appearance of a stationary ground target whose movement and size changes reflected the aircraft's movement approaching and eventually bypassing the specific target location. Such procedures were followed for all 30 targets.

Although the description of the boundary lines overlay preceded the description of the target overlay in this report due to the greater frequency of use of the former, the Model 70-E program executed target-embedding first, and boundary lines overlaying second. For the majority of frames in which boundary lines overlays,were necessary in the absence of target overlay, target embedding was skipped by simply directing the program to its second execution only.

The process of annotating frames with the necessary ranging and target detection information continued until all 30 targets were embedded properly. An elapsed real time of four seconds (i.e., 40 frames) was dictated as the shortest interval between the offset of one target and the onset of the next one. This entire procedure resulted in a film of four minutes 56 seconds. A total of 34 200-frame video discs of background imagery were used.

The resulting imagery with specified annotations as embedded by the Model 70-E image computer and displayed onto the Tektronix 650 A-1 monitor was recorded on video cassettes by a Sony U-Matic video cassette recording unit. Because of the image processing computer program in the Model 70-E, the three different types of annotations (see above) for each frame were recorded in succession. This necessitated a selective rerecording of the video cassettes back to video discs so that successive recordings of similarly annotated frames could be grouped. That is, a selective editing process of the video cassettes to video discs resulted in three different tape segments with sequential and similarly appearing (i.e., same type of annotation) frames. The discs were recorded back to video cassettes for final editing to eradicate all imagery overlap and produce a final product continuous flight simulation film segments.

The editing facilities used were at Gillette Children's Hospital, St. Paul, Minnesota: Two Sony 2860 video cassette recorders, a Z-6 Video Media mixing control unit, a Telemedia 36-10A character generator, and a Panasonic WJ 200 series video switcher.

This process resulted in three five-minute film segments, one for each Model 70-E function described above. The black-and-white film segment with dashed lines was employed in the black-and-white combined experimental condition, and the color band imagery was employed in the color-combined experimental condition. No further imagery were then needed for these experimental conditions. However, this was not the case for the remaining imagery display developed. The black-and-white imagery with no boundary lines was employed in both the single- and double-monitor uncombined conditions but not exclusively. This imagery, with the absence of range-finding data, yielding only target detection data, represented IR simulation only. Consequently, an additional imagery display simulating a radar display needed yet to be developed for the uncombined conditions. The procedure for developing this final imagery display follows.

The radar imagery display developed for use in uncombined conditions, was distinctively different than those described earlier. Consequently, an entirely different developmental process was employed. The radar-display imagery, unlike the realistic-looking aerial photography imagery, was symbolic in nature. A simulated sectioned PPI radar pattern was used as the background imagery for this display (see Figure 24).

The display sheets had the radar grid and were correlated with the aerial video tapes and were updated every third frame. Point-of-impact information (i.e., appropriately placing a cross hair in one of the three sections of the display) and target-detection information (i.e., symbolic representations of each target with appropriate highlighting annotations) were hand drawn on each sheet. These hand-drawn annotations reflected the identical information on the parallel IR simulation display. The two displays differed only in their mode of presentation (symbolic versus realistic). Approximately 300 sheets were developed.

With the use of the Telemation 1100 camera, each radar simulation sheet was projected onto a Tektronix 650 A-1 monitor. Each projected image was then recorded onto the Arvin Echo video disc player/recorder. These video disc recordings were then transformed onto video cassettes to prepare the imagery for the final editing process. This process employed the Gillette Children's Hospital editing facilities as described earlier.

The last procedure was to attach a leader tape to the beginning of both the IR simulation display tape (black and white with no boundary overlays), and to the radar simulation display tape. The leader tape countdown assured that both tapes were run exactly simultaneously in the uncombined conditions for which they were eventually used.

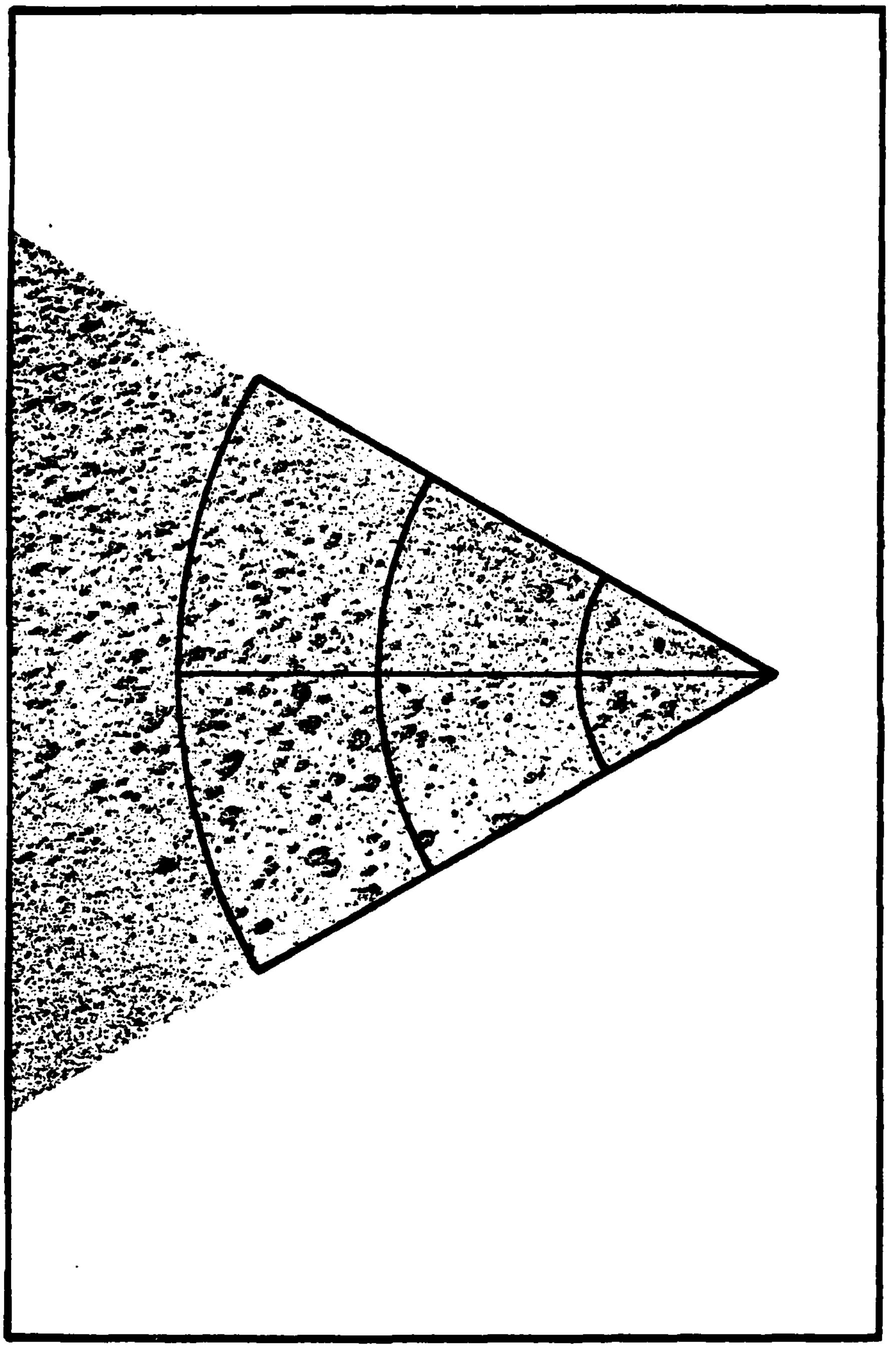


Figure 24. Simulated Radar as Background Imagery

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SECTION 7
TRAINING PROCEDURE

All subjects were trained for a period prior to each experimental condition. Since each subject participated in two experimental conditions, two training sessions were given each subject. While the second training period lasted approximately 15 minutes, the first extended for up to 45 minutes. The more brief second training session was largely due to the subject's familiarity with the work, gathered from the similar nature of the tasks already completed in the first experimental condition. In fact, the tasks in both experimental sessions were identical, only the conditions for them changed.

Subjects were expected to perform three tasks concurrently during *each experimental condition*. The tasks were ranked according to their significance: 1) point of impact, 2) target detection, and 3) tracking (See Experimental Procedure for Detail). Subjects were trained for these tasks in the reverse order of their significance. to this experiment. That is, subjects were first trained for the tracking task, then the target detection task, and finally the point of impact task. Certain aspects of the training session varied from subject to subject, depending upon the experimental conditions involved and the order in which they were to be conducted. Other aspects of training remained constant across all subjects at all times.

The first part of the training session addressed itself to the tracking task, the least significant task. Across all subjects for all experimental conditions, this training segment remained uniform. All subjects, prior to the first experimental condition, were given five one-minute training trials at the task. In all but three instances, subjects stabilized their accuracy by the end of the fifth trial. For those three subjects who continued to better their performance through all five trials, two additional one-minute training trials were added. All three subjects then displayed performance stability.

The tracking task remained unchanged in the second experimental condition across all subjects as well. Training for the tracking task prior to the second experimental condition consisted of two one-minute trials at the tracking task. All but four subjects reached their baseline performance level within this alotted time. The four subjects who continued to better their tracking performances were given a single additional one-minute training trial. A baseline performance level was then reached by each of these subjects.

Following the training trials preceding both the first and second experimental conditions, subjects were given the opportunity to question any areas of uncertainty concerning the tracking task. The training session continued on the second task, target detection, only when each subject acknowledged a complete understanding of the tracking task.

The second part of the training session addressed the task of target detection. This training component was formatted consistently across all subjects, but varied in the stimulus material presented, depending on the experimental condition being addressed.

All subjects performed in both a combined and an uncombined condition (see experimental procedures for detail). Combined conditions were either in color or black and white. Uncombined conditions were either single- and double-monitor displayed. These variables determined the nature of the material presented during this, the second part of the training session.

All subjects were initially exposed to a 15-second video clip of the dynamic nature of the five-minute video tape they were to see during the experimental condition. Prior to viewing this video clip, they were instructed to attend to the specific features of the imagery altitude, speed, and terrain relevant to their integrating with their tasks during the experiment. Subjects in the color condition viewed a colored film segment, while subjects in the black-and-white conditions viewed black-and-white film.

All subjects across all conditions were then exposed to still photographs of each of the possible targets to be detected. These displays exposed the subject to the largest possible target size that would ever appear during the experimental condition. That is, although the subject would be exposed to smaller pictures of each of the targets during the experimental condition, he would never see larger sizes of the targets that those shown during the training period. Targets were then presented to the subject in highlighted conditions. Although not all target-by-highlighting combinations were shown, a representative sample of these combinations were viewed and an explanation of the remaining possible target-by-highlighting types presented. Training did not continue until the subject expressed a complete understanding of the possible target shapes and highlighting combinations that he may have had to view during the experimental condition. For subjects

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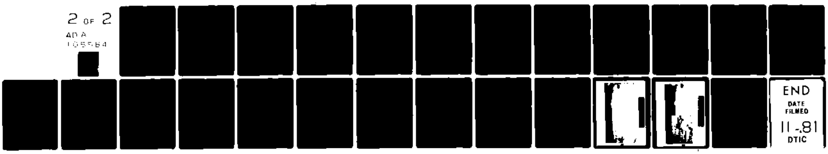

in the color condition, all targets and highlightings were displayed in color. For subjects in black-and-white conditions, all displays were in black and white.

Prior to the showing of this video clip, subjects were asked to attend to specific features of the display containing pertinent information for their experimental condition, duration time of targets on the screen, changing sizes of targets, constant size of highlighting shapes, contrast, and color. Once again, subjects in the color condition viewed a color-video clip while subjects in black and white condition viewed a black and white video clip.

After the video clip presentation, any questions on the task were answered and a second, similar video clip was shown. Subjects were now asked to respond by identifying the targets by simply calling out their names just as they would be required to do during the experimental condition. Feedback (correctness or incorrectness of response) was given to the subject after each response. Again, color-condition subjects viewed a color video clip and black and white-condition subjects viewed a black and white video clip.

When subjects were run under the combined conditions, the second section of the training period ended. When they were run uncombined conditions, an additional training period was needed to explain the added (radar)display and its function for the target-detection task.

All subjects were run in both combined and uncombined conditions. However, some subjects did a combined conditions first and an uncombined condition second while others performed in the opposite order. Consequently, all subjects were exposed to the additional (radar) display training period, however, for some, this occurred in the training period preceeding the first conditions, while for others this occurred in the training period preceeding the second experimental condition.

The additional training period needed for the target-detection task in the uncombined conditions consisted of familiarizing the subjects with the radar signature for the targets, both highlighted and unhighlighted, and the background against which they were to be dynamically displayed. Subsequently, a small video clip was shown integrating both target movement and a dynamic background display. The subjects were instructed that, during the experimental condition, this display would be used concurrently with the one previously viewed. Similarities and differences in information delivered from the two monitors were elaborated upon. After the subjects understood the nature of the dual-monitor task and the added instructions necessary for it, there was a brief practice trial. Viewing the second (radar) display only, subjects responded to a small video clip by calling out targets just as they would be asked to do during the experimental condition. Feedback (correctness of response) was given and all subsequent questions answered. This concluded, the extended target detection training offered to all subjects when run in the uncombined conditions only.

The final section of the training session addressed the point-of-impact task, the most important one. Subjects in uncombined conditions received different training that subjects in the combined conditions. Since all subjects ran in both combined and uncombined conditions, all subjects were exposed to both training sections. Subjects were exposed to one during the training session preceeding the first experimental condition, and to the other in the training session preceeding the second experimental condition. The order in which subjects experienced training depended upon the order in which they were run.

Training for the target-detection task only varied from the combined to the uncombined condition in that the information needed for the task was differentially presented in the different monitor displays. The training, however, was similar.

For both training sections, the experimenter explained the purpose and function of the task and how each condition displayed the needed information. Subject responses to the task were explained and training trials followed. Questions were answered until the experimenter perceived each subject completely understood the task. At that time, an intergrated practice task (point of impact and target detection) was administered. Subjects responded to the trial task in the same way as in the experimental condition. Subsequently, feedback (performance, accuracy accounts) was given to each subject. Again, subjects were then permitted to ask any questions concerning all three tasks. When each question was adequately answered and the experimenter perceived the subject to the total comprehension of his experimental condition tasks, the training session ended.

SECTION 8
CONTROL OF THE EXPERIMENT

The experiment was conducted in the man/machine laboratories under the control of an Eclipse Data General Computer. During the development of the imagery, a code was added across the bottom of each frame to indicate the contents of that frame. The code consisted of 10 small squares, which were either black or white. The 10 squares represented the 10 possible conditions: points of impact (near, intermediate or far); types of targets (helicopter, task, burner, or none), and highlighted conditions (square, triangle, circle or none).

Ten photocells were placed across the bottom of the CRT. The computer read the status of these cells (on or off), the position of the point of impact switch (near, intermediate or far) and the position of the joystick (X and Y). In addition, a voice-recognition system recorded target recognition responses from the subjects, and provided the computer with the time when the utterance began and the type of target detected.

The codes on the tape allow response time to be measured within two video frames, or approximately 66 milliseconds. The capstan driven video tape recorder(s), one for combined and two for uncombined displays, were driven by a common time base corrector and synchronized within one frame. The recorders were keyed and started on timing frames ahead of the actual imagery. At the end of a run, a high-speed printer listed the times of the changes and responses.

The two-dimensional tracking task was generated in a Nova Data General computer and displayed on a stroke writing Megateck display. A high-resolution video camera focusing on the stroke writing display, converted the tracking task to a 525-TV-line raster format. A video mixer inserted the tracking task in the upper center of combined and IR displays. The white-tracking task on the darker imagery produced a high contrast. The computer also calculated RMS tracking errors.

A wood mockup was fabricated to hold the displays and controls. A 12-inch high-resolution color monitor at eye level presented both combined-display conditions, multifunction conditions and FLIR uncombined data. A 13-inch black-and-white monitor just below the color monitor presented the radar data for the multi-display condition. A trigger switch operated by the index finger on the tracking stick allowed the operator to select either the FLIR or radar display during the multifunction conditions.

SECTION 9
RESULTS

Four performance measures were recorded for each subject's display conditions:

1. Tracking score indicating the subject's proportion of single-task performance that was retained under multiple task (tracking, detecting, impact monitoring and switching) conditions. This was a number between 0.0 and 1.0, based on measured RMS performance in the two conditions.

2. Target Detection Time indicating time from onset of target to vocal response identification.

3. Correct Identifications indicating the number of targets correctly identified under the trial. This was a number out of 32 possible targets.

4. Point-of-Impact Shifts indicating the number of correct changes in the toggle position to align with the cursor position. This was a number out of 50 possible changes.

These variables were analyzed several ways across several groupings in the experimental design. Recalling our design with four major conditions:

Condition	Sensor Description
1	Color Combined
2	Uncombined, one monitor
3	Black and White, Combined
4	Uncombined, two monitors

We see that conditions (1) and (3) are "combined" displays, and that (2) and (4) are uncombined displays. In the following analyses, these conditions were compared and contrasted in several ways. The analyses included:

- Correlational analysis of all dependent variables
- Combined vs uncombined display comparisons
  - Unvariate analysis
  - Grouping of subject scores
  - Multivariate analysis
- Display condition comparisons
- Color vs. black-and-white comparisons
- Sensor detections/highlight comparisons

The following section describe these analyses and results.

CORRELATIONAL ANALYSES

To assess the degree of relationship between our four performance measures, correlation scores were obtained across all subjects. The three tables are shown in Table 6. They are divided into combined conditions (1) and (3) and uncombined conditions (2) and (4) and total across all four conditions. The correlations are

TABLE 6. CORRELATION COEFFICIENTS

Combined

	TR	RT	CR	POI
TR	-	0.30664	-0.09906	0.06072
RT	-	-	0.29043	0.13648
CR	-	-	-	0.08956
POI	-	-	-	-

Uncombined

	TR	RT	CR	POI
TR	-	0.16648	-0.19513	-0.26782
RT	-	-	0.00082	0.11845
CR	-	-	-	0.17402
POI	-	-	--	-

Total

	TR	RT	CR	POI
TR	-	0.23281	-0.14476	-0.10191
RT	-	-	0.14331	0.12544
CR	-	-	-	0.12970
POI	-	-	-	-

generally low and below the level of significance at the $p < 0.05$ level ($r = 0.296$). One correlation, between tracking and response time, was above this level (0.307), indicating a weak, positive relationship between these measures. Generally, the measures recorded showed little interrelationship indicating a measurement of different human capabilities.

COMBINED VERSUS UNCOMBINED DISPLAY COMPARISONS

Unvariate Analysis -- The means for the four performance measures across combined and uncombined conditions are presented in Figure 25. Standard deviations are shown in brackets. The confidence level is shown in the upper right corner of each graph. All four measures showed statistically significant differences between the two condition groups.[1] Tracking performance, correct identifications, and point-of-impact changes were all superior under combined display condition. However, an analysis of the stimulus material indicates a possible explanation for this apparent contradictory effect. The FPI radar image allowed early target recognition reducing time to respond. This observation indicates that highlighting the area of interest on the primary display is not sufficient and that the combined display must contain inserts of other sensor data from secondary sensors.

The other three measures indicated the expected results. Subjects had more residual attention for tracking combined displays. Combined displays enhanced the ability of the subjects to identify targets correctly.

1 A dependent or paired-data t-test was performed to assess the condition differences with df=31.

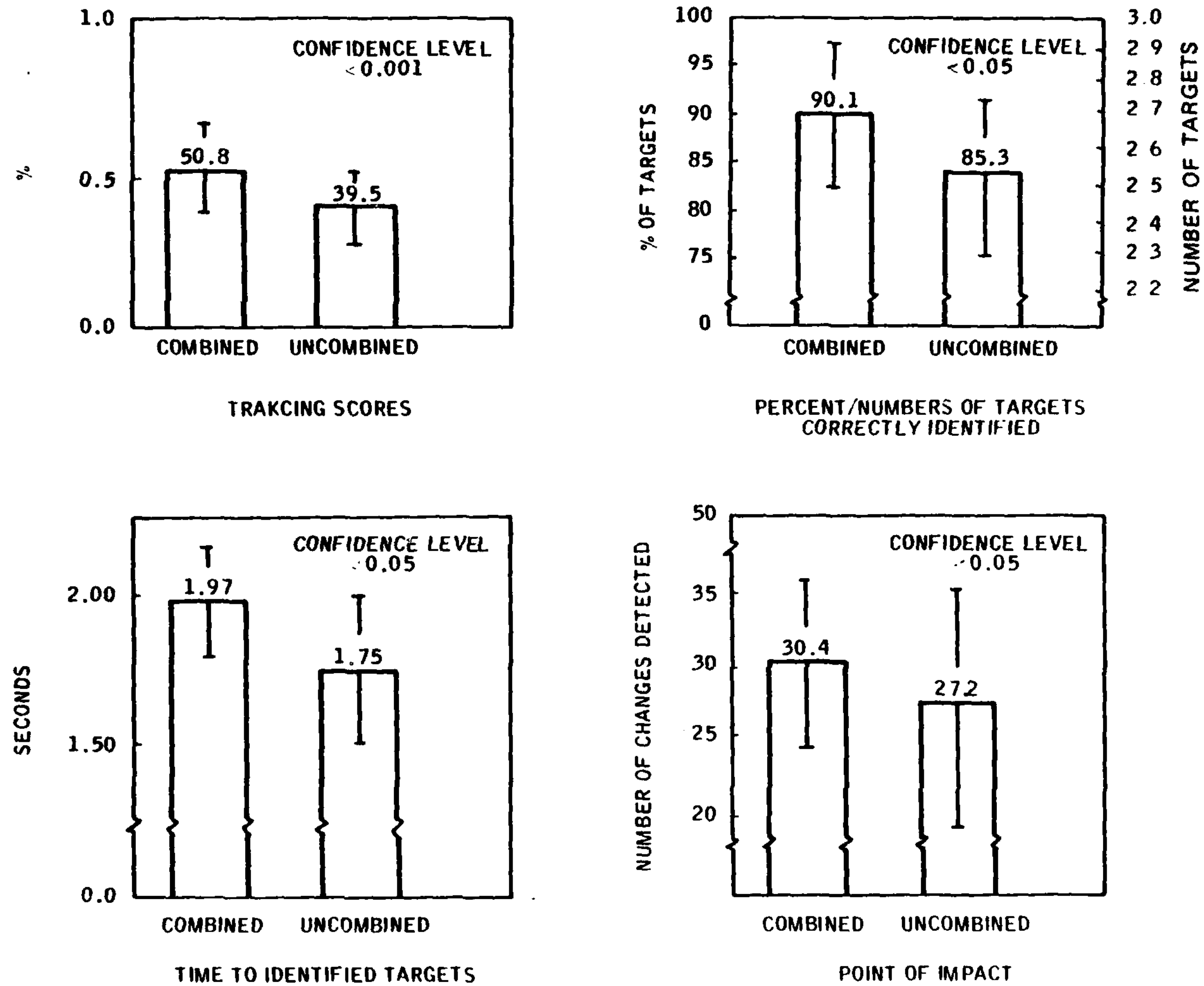

Figure 25. Combined versus Uncombined Graphs and Confidence Levels

Subject Data Analysis by Grouping -- The subject's performance on all four measures was ranked. From this rank ordering, two groups were established: one with the highest scores, and one with the lowest scores. Each group contained approximately 20 scores. However, ties did not permit exact cutoff points. This analysis, as shown in Table 7, indicates that two out of three high-performance scores on tracking and correct target identification occurred in the combined condition. It also indicates by the same margin that poor performance occurred during the uncombined condition. The response time measure also supported the contention that the radar sensor data provided earlier target recognition. The point-of-impact analysis indicated a much less pronounced difference between combined and uncombined conditions. During the training period, the subjects were instructed to give the highest priority to the point-of-impact tasks (this task was related to terrain avoidance and aircraft altitudes). This instruction, if followed, would produce small differences between high-priority tasks and larger differences between the low-priority and secondary or "workload" tasks.

Multivariate Analysis -- To provide a more accurate description of the performance of subjects in a multi-dependent variable situation such as this study, one should consider combining scores in a linear fashion to maximize group differences and assess the contribution of each variable to this difference. Multivariate discrimination analyses allows us to combine data from several dependent scores and create a new variable which can be regarded as "performance." The data from this experiment was analyzed to maximize the group differences between combined and uncombined display conditions.

TABLE 7. COMBINED VS. UNCOMBINED HIGH/LOW GROUPS

TRACKING

LOW GROUP			HIGH GROUP		
Combined	3	15%	Combined	14	70%
Uncombined	17	85%	Uncombined	6	30%
Total	20		Total	20	

CORRECT TARGET IDENTIFICATIONS

LOW GROUP			HIGH GROUP		
Combined	7	32%	Combined	15	68%
Uncombined	15	68%	Uncombined	7	32%
Total	22		Total	22	

TIME TO IDENTIFY TARGETS

LOW GROUP			HIGH GROUP		
Combined	13	65%	Combined	3	15%
Uncombined	7	35%	Uncombined	17	85%
Total	20		Total	20	

POINT OF IMPACT

LOW GROUP			HIGH GROUP		
Combined	9	41%	Combined	10	50%
Uncombined	13	59%	Uncombined	10	50%
Total	22		Total	20	

Figure 26 is a composite of standard score data distributions for all four performance measures and our discriminate scale,"performance." The plots show that, although the individual measures indicate a difference in distributions for combined vs. uncombined displays, the multivariate analysis markedly increases the distance between distributions.

The major product in the discriminate analysis is a set of weights indicating the relative sensitivity of the dependent measures to group differences. These weights indicate the best linear combination that accentuates the differences of the uncombined groups. The analysis of our data revealed the following equation for combined data:

$$\text{Performance} = 0.67\ TR + 0.46\ RT + 0.48\ CI + 0.32\ PI$$

where TR is tracking, RT is response time, CI is correct identification and PI is point-of-impact data. (The function was significant at the $p < 0.05$ level.)

The function shows tracking to be the most sensitive to display condition changes, followed by RT and CI, and finally PI. This progression corresponds to the subject's priorities between tasks, and to the instructions. PI was to be regarded as more important than either target recognition/detection or tracking. Subjects were able to devote less attention to tracking in the uncombined display conditions, i.e., demonstrating less "reserve" capacity for a low-priority task. Combined displays allowed a *good* performance on even the lowest priority task, while maintaining or increasing the performance on other tasks.

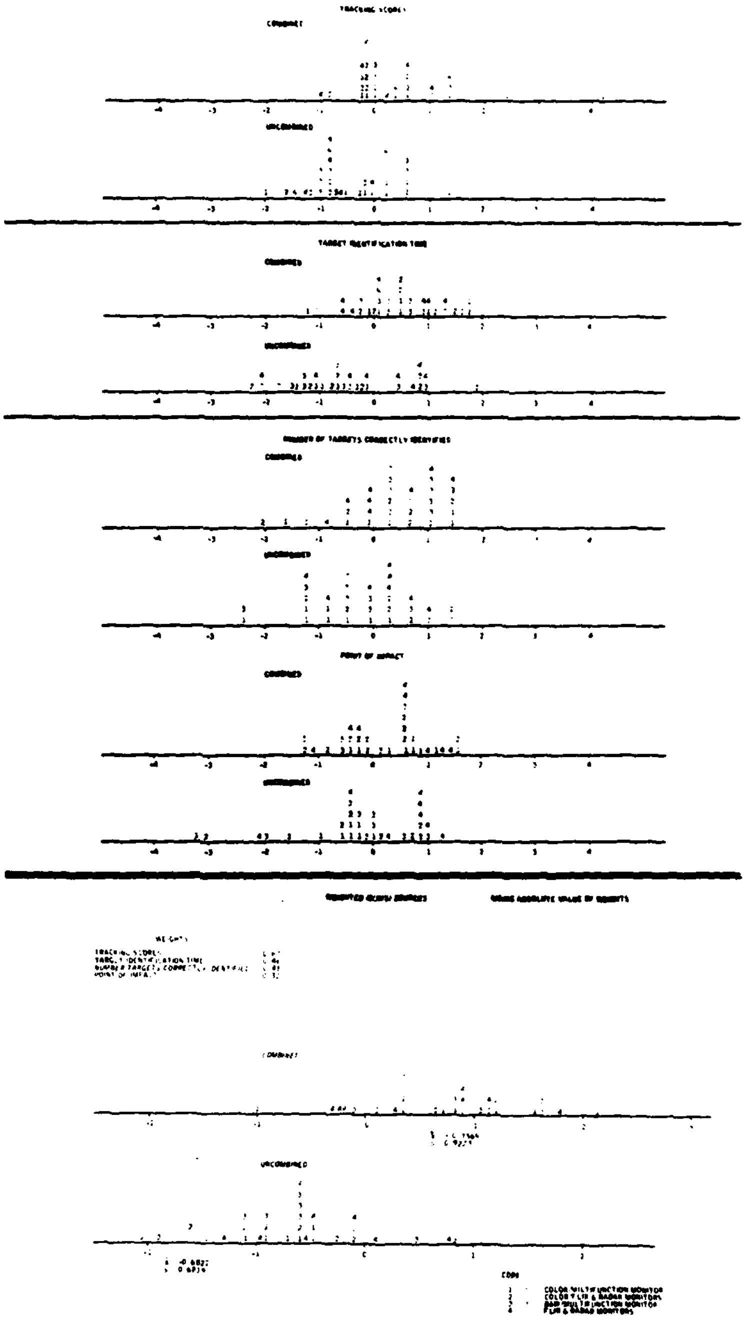

Figure 26. Combined versus Uncombined Standardized Score Data

DISPLAY CONDITION COMPARISONS

Comparisons of Combined and Uncombined Display Conditions -- The four display conditions were compared in pairs by t-tests (df=7) of the various measures. These data are presented graphically in Figure 27. The levels of significance of each comparison are shown by the *'s indicating the 0.05, 0.01, and 0.001 levels.

Tracking scores were significantly better in all comparisons, except for the Color Combined-vs.-Multifunction Monitor display comparison, and these conditions showed differences in the expected direction. Tracking was consistently better across the combined display conditions.

Target response times were significantly lower in only two condition comparisons: Color vs. Combined FLIR & RADAR Uncombined, and Color Combined vs. Multifunction Uncombined. The other two conditions (Black-and-White Combined vs. both Uncombined conditions) showed only small differences.

Target's identified were significantly more in the Color Combined vs. Multifunction, and Black-and-White Combined vs. Multifunction display comparisons. The other conditional comparisons revealed only small differences.

Point of impact changes were significantly higher in only one comparison: Color Combined vs. Multifunction Uncombined.

Although some comparisons were not significant, most were in the expected direction.

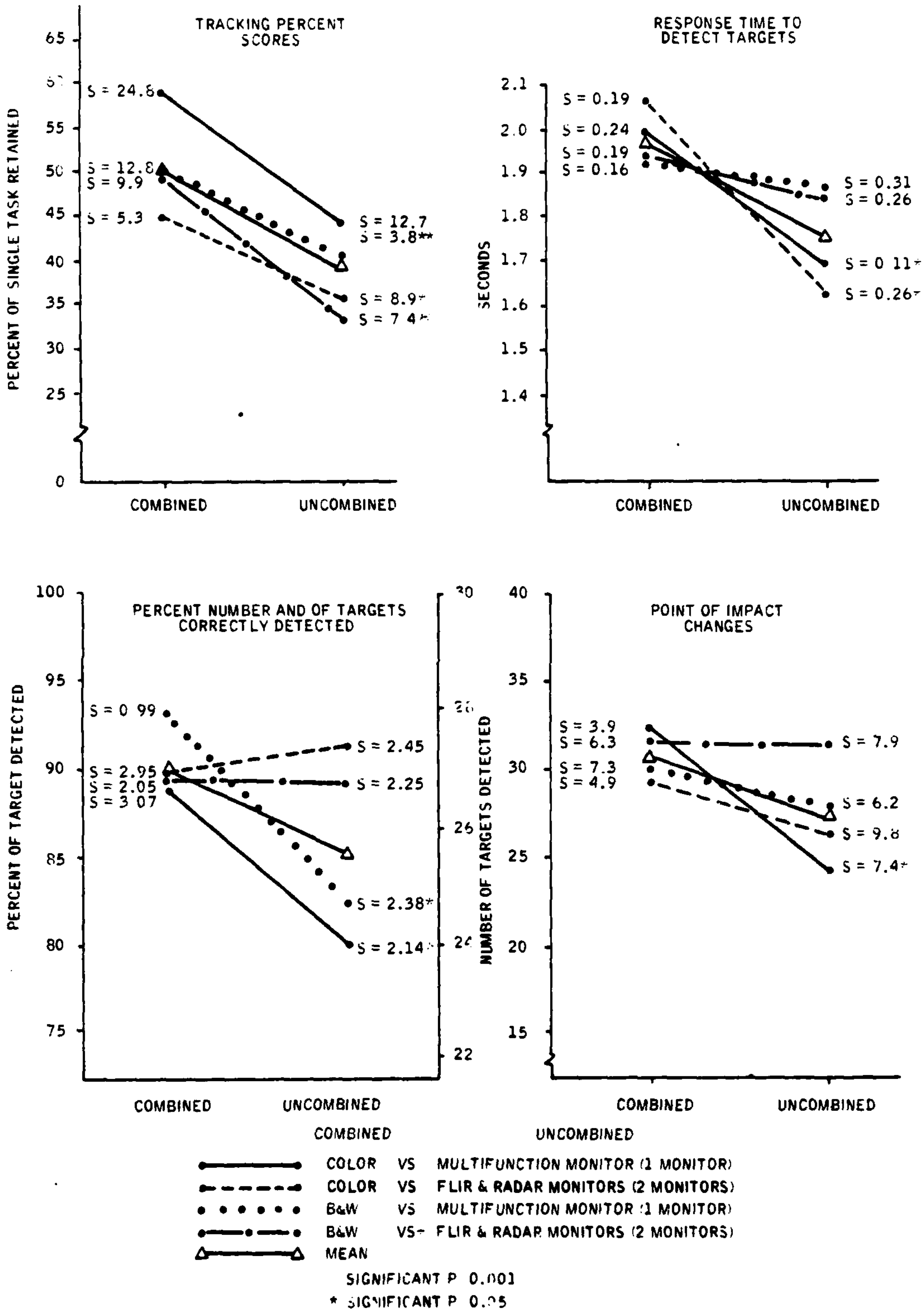

Figure 27. Combined versus Uncombined Display Conditions

COMPARISON OF COLOR AND BLACK-AND-WHITE DISPLAYS

The two experimental conditions combining sensor information were compared in this analysis. This was a comparison of the color combined vs. black-and-white combined displays (Conditions 1 vs. 3).

An independent groups t-test (df=30) was performed on all four performance measures. None of the tests showed statistical reliability at $p < 0.05$ level, although number of targets correctly identified and target response times showed trends favoring the black-and-white system.

SENSOR DETECTIONS/HIGHLIGHT COMPARISONS

An analysis compared the combined/uncombined detection performances of the three highlight methods:

1) Radar-only highlight
2) FLIR-only highlight
3) Both FLIR and radar highlight

Data was collapsed across the three target types. Means for the combined and uncombined conditions are presented in Table 8.

Radar-only Highlight -- Our analysis of the radar highlight method showed significantly faster target response times and a trend toward fewer correct identifications for the uncombined displays. Times were shorter in uncombined displays because the radar display used to highlight on uncombined, provided target

TABLE 8. TARGET DETECTION CONDITIONS

TARGET RESPONSE TIMES (SECONDS)

Target Detected By	Mean Combined	Mean Uncombined	Confidence Level
Radar Only (Δ)	1.89	1.54	P<0.001
FLIR Only (□)	1.96	1.82	P = 0.051
Both Radar & FLIR (O)	1.93	1.69	P<0.001

NUMBER OF TARGETS CORRECTLY RECOGNIZED
(out of 6 possible targets)

Target Detected By	Mean Combined	Mean Uncombined	Confidence Level
Radar Only (Δ)	5.19	4.66	P = 0.10
FLIR Only (□)	5.44	5.13	P > 0.10
Both Radar & FLIR (O)	5.50	5.34	P > 0.10

information sooner than on the combined display. Radar-only highlighted targets were more correctly identified on the combined display, i.e., target signature was more defined on these displays.

FLIR-only Highlight -- The FLIR-only detected targets tended to be recognized earlier on the uncombined displays, although this result was not significant. A possible explanation for the trend is that after the subjects found a highlighted FLIR target on the uncombined FLIR monitor, they jumped to the uncombined radar monitor for a rapid confirmation. In this condition, approximately the same number of targets were correctly recognized in the combined and uncombined modes.

FLIR and Radar Highlight -- When both sensors detected a target, the recognition times were significantly shorter in the uncombined condition. This evidence continues to support the contention that the subjects were using the radar display for early recognition. Again, an equal number of targets were recognized in both combined and uncombined conditions.

SUMMARY

This data indicates that combined displays must present the most appropriate target display information for each short increment of time. The data further suggests that the operators may desire to switch between sensors IR, radar and millimeter wave.

In addition, handoff and automatic selection of the sensors to be displayed must be developed. That is, the radar is best at long ranges, however, as the range is reduced, the FLIR or other sensors become more appropriate. The difficult area is in the transition when more than one sensor is providing useful data.

SECTION 10
RECOMMENDATIONS

In addition to conducting the laboratory tests, the multisensor concepts were presented to both Navy and Air Force pilots for comments and criticism. The concepts were also evaluated in relation to display content and usefulness on close-air-support missions. Therefore, the following recommendations are based on user comments, experimental data, and analytical data.

1. The combined display must attempt to present the world as viewed from the cockpit. Abstract displays which do not relate to the real world, or which require interpretation create confusion when pilots use the display and intermittently fly VFR.

2. Keep it simple - Display only the high-priority, essential information. Nonessential data only masks the key information.

3. The pure addition or overlay of sensor data (IR, LLTV, Millimeter wave and radar) does not enhance, but degrades the targets. The direct overlay approach tends to obscure the critical data in each display.

4. Use a black-and-white display to transmit high-frequency information or imagery. Pseudo-color tends to produce slower response times.

5. Color should be used to reinforce symbology, not as the primary method of coding. That is, if color were not present, no data would be lost from the display.

6. One display format will not serve for navigation, pop-up and attack. The mission requirements change, therefore, the optimum display format also changes.

7. The combined display must present the most appropriate sensor information. One display highlighting by other sensor is not sufficient.

8. The display must provide a smooth transistion as the mission changes, navigation to pop-up to attack and also as the appropriateness of the sensors change, radar to millimeter wave to FLIR to LLTV.

9. The display should indicate which sensors are above a threshold for the area of interest.

10. The display should emphasize threat-radar trackers at missile sites.

11. The combining of the sensor should not use symbols which obscure critical information. Cross hairs may block most of a target.

The combined multisensor displays studied and evaluated were preliminary concepts. The following two advanced concepts were developed by using the 11 preceding recommendations. Figure 28 is a display concept for a high-speed, low-altitude penetration segment of the mission. Figure 29 shows the same display configured for the pop-up segment. The displays have the following features:

- Range Zones - The near zone is indicated by a series of small red and white circles and the far zone by green and white dashes. If the colors were not present, the zones line are still distinguishable by the shape (circles and dashes).

- Background - To maintain the real-world relationship, the sensor that best visually represents the real world is used as the background for the display.

- Target Highlight - When the output of a sensor exceeds a threshold, the sensor data is inserted on the display. These squares, with an increased dynamic gray scale, contain the actual sensor data, not the highlighting of the background sensor. If more than one sensor exceeds the threshold level, the box will contain the image from the sensor highest above the threshold level. Color bar(s) on the sides of the box indicate which sensor detected the area. Again, if the color is lost, the bar(s) location left, right, top or bottom still indicate the sensor(s). Also, the bar does not obstruct the contents of the square.

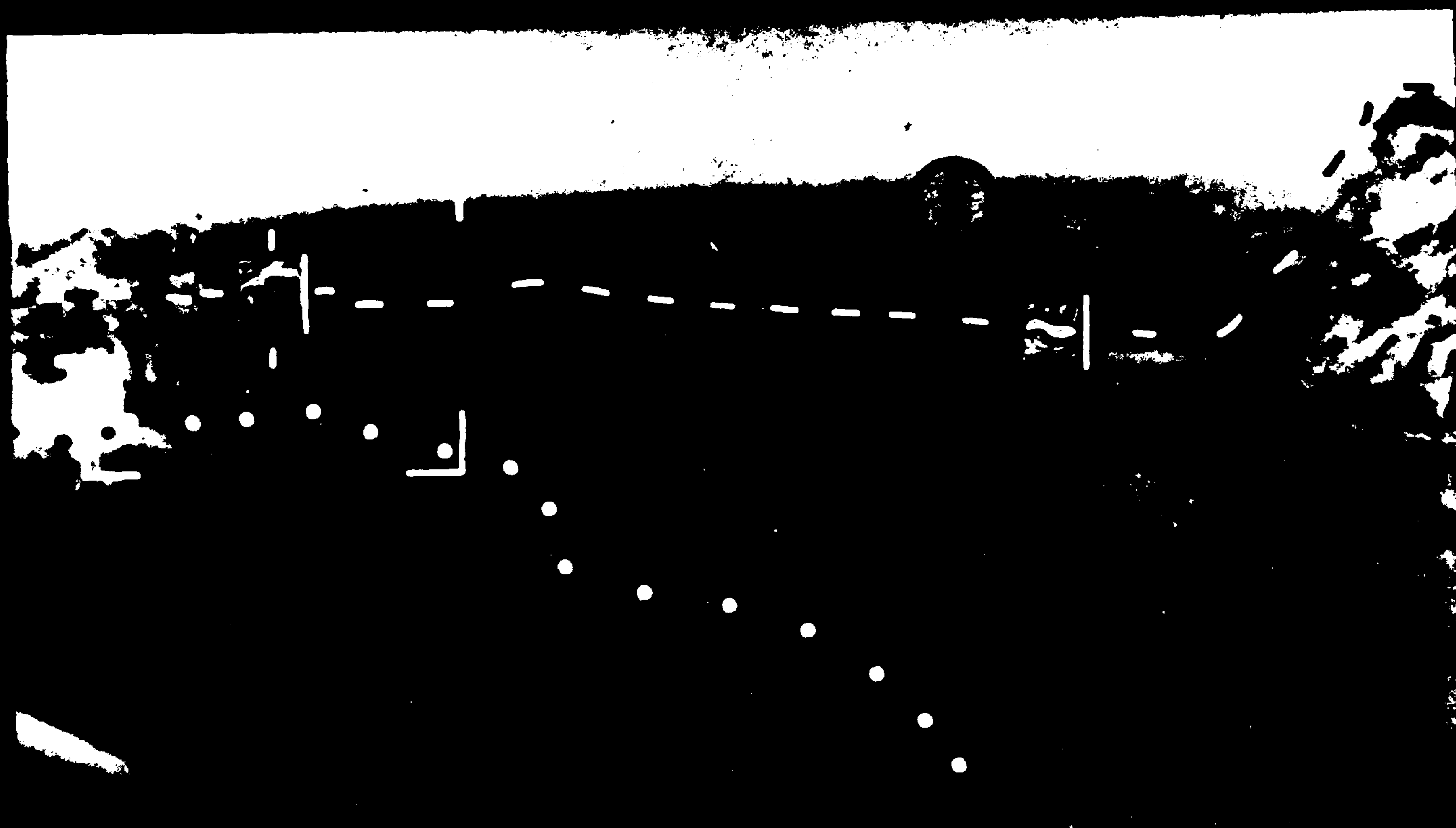

Figure 28. Advanced Combined Display Concept

Figure 29. Advanced Display Concept with Narrow Field-of-View Insert

- <u>Threat Sensors -</u> These areas of strong emissions are highlighted by a red circle. The circle is used only to indicate threats.

- <u>FOV</u> - A wide FOV is required to fly the aircraft, and the narrow high-resolution FOV is required for target related activities. The system contains high resolution sensors which are covering the area within the cornered rectangle. This rectangle is centered on an area that exceeds a threshold. If more than one area exceeds a threshold, the cornered rectangle jumps around the threshold areas until commanded to stop by the pilot. At this time, the area becomes magnified about its center point (Figure 29). Targets often come in clusters, therefore, the larger area within the covered rectangle was used rather than the smaller threshold area.

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